la era del ecoprogreso
XVII CONGRESO AAPRESID

Alan Franzluebbers

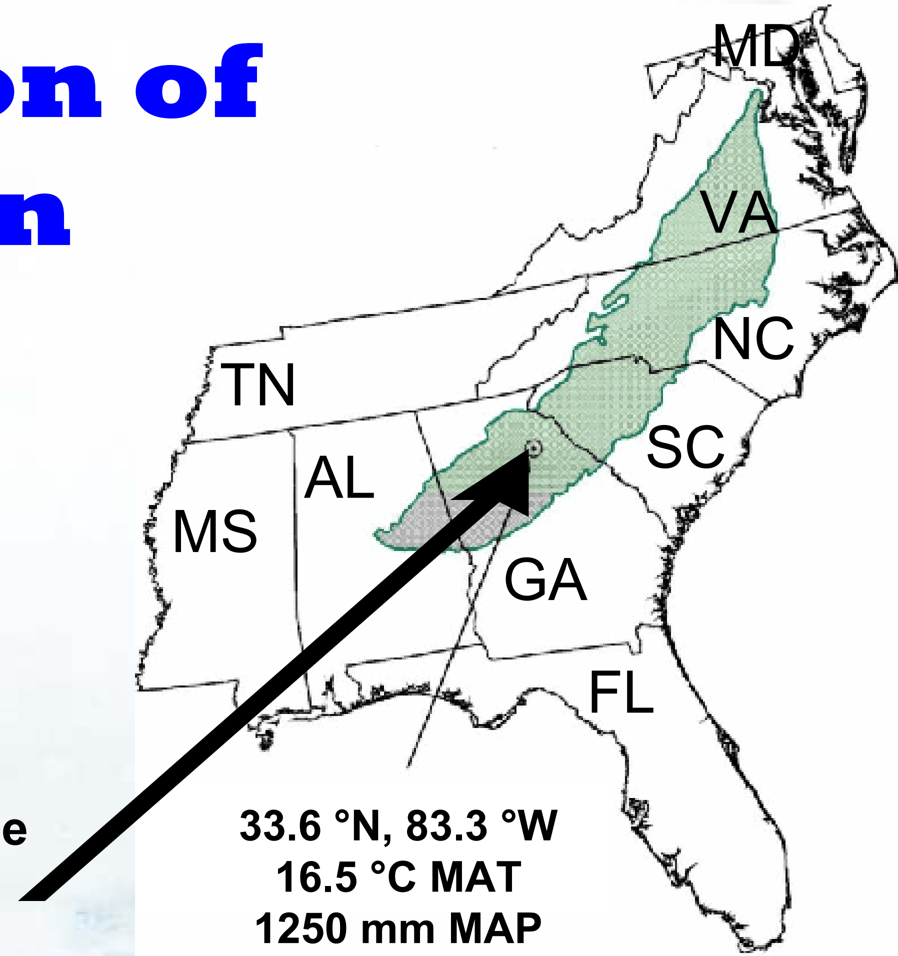
Ph.D., Ecologist

alan.franzluebbers@ars.usda.gov

Soil Organic Carbon as an Expression of Sustainability in Conservation Agricultural Systems

USDA ARS

Watkinsville Georgia



la era del ecoprogreso
XVII CONGRESO AAPRESID

Agricultural ecosystems

People

Productive

http://i.ehow.com/images/GlobalPhoto/Articles/4606590/cornucopia-main_Full.jpg

Air

…and their fundamental elements

Soil

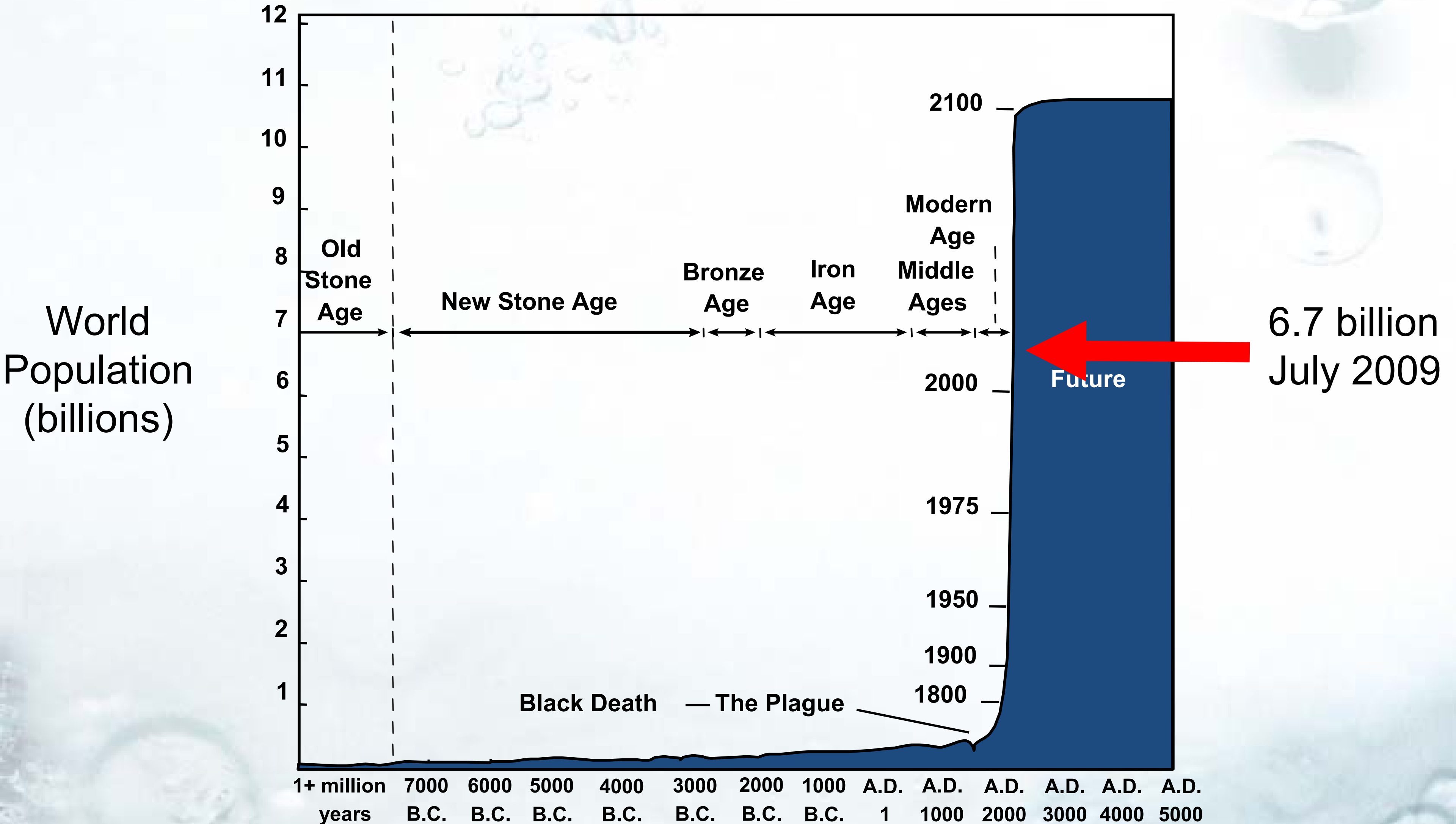
Water

Research to promote resource efficiency and preserve/restore environmental quality

Profitable

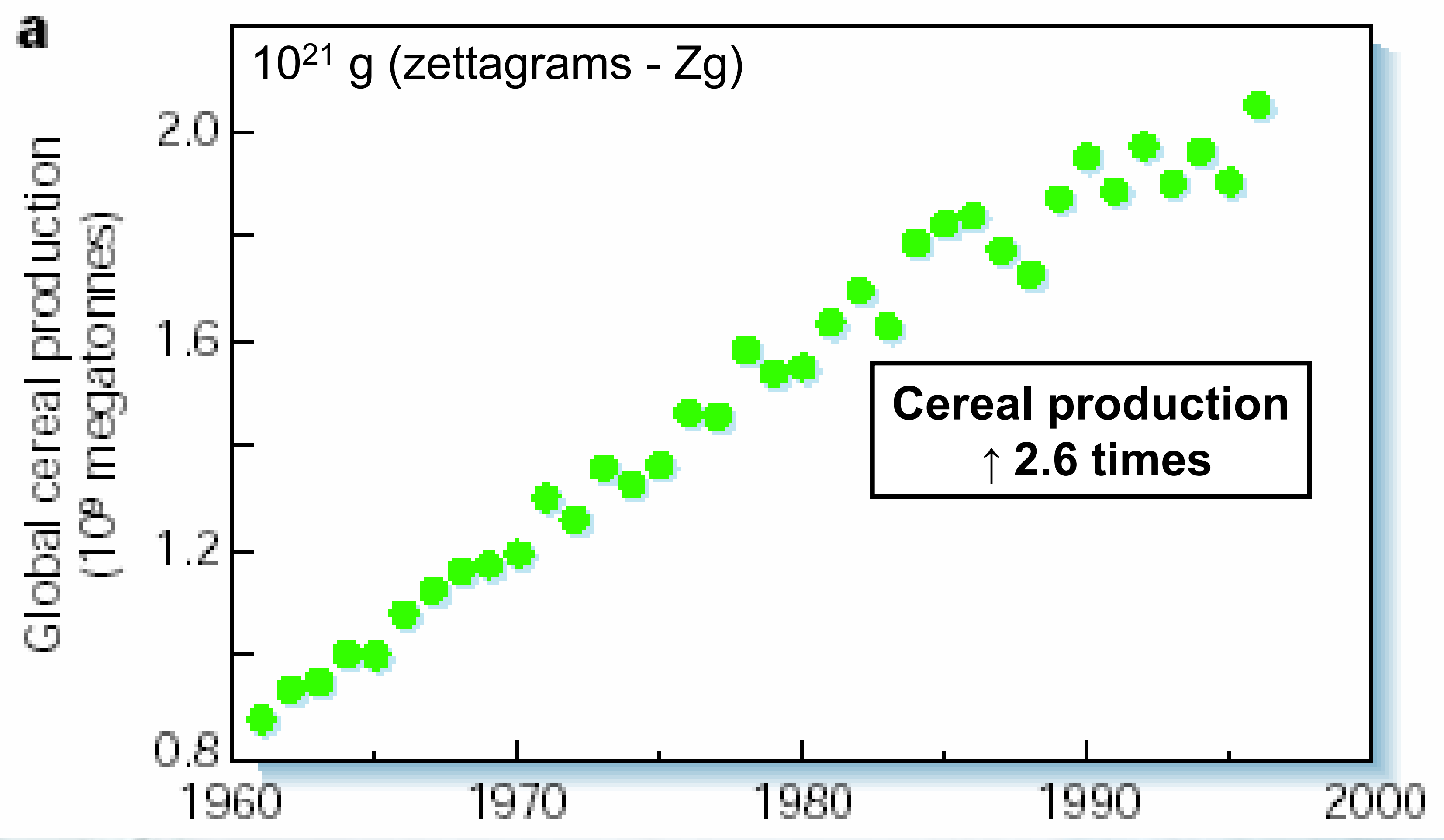
Protective

Consider human population



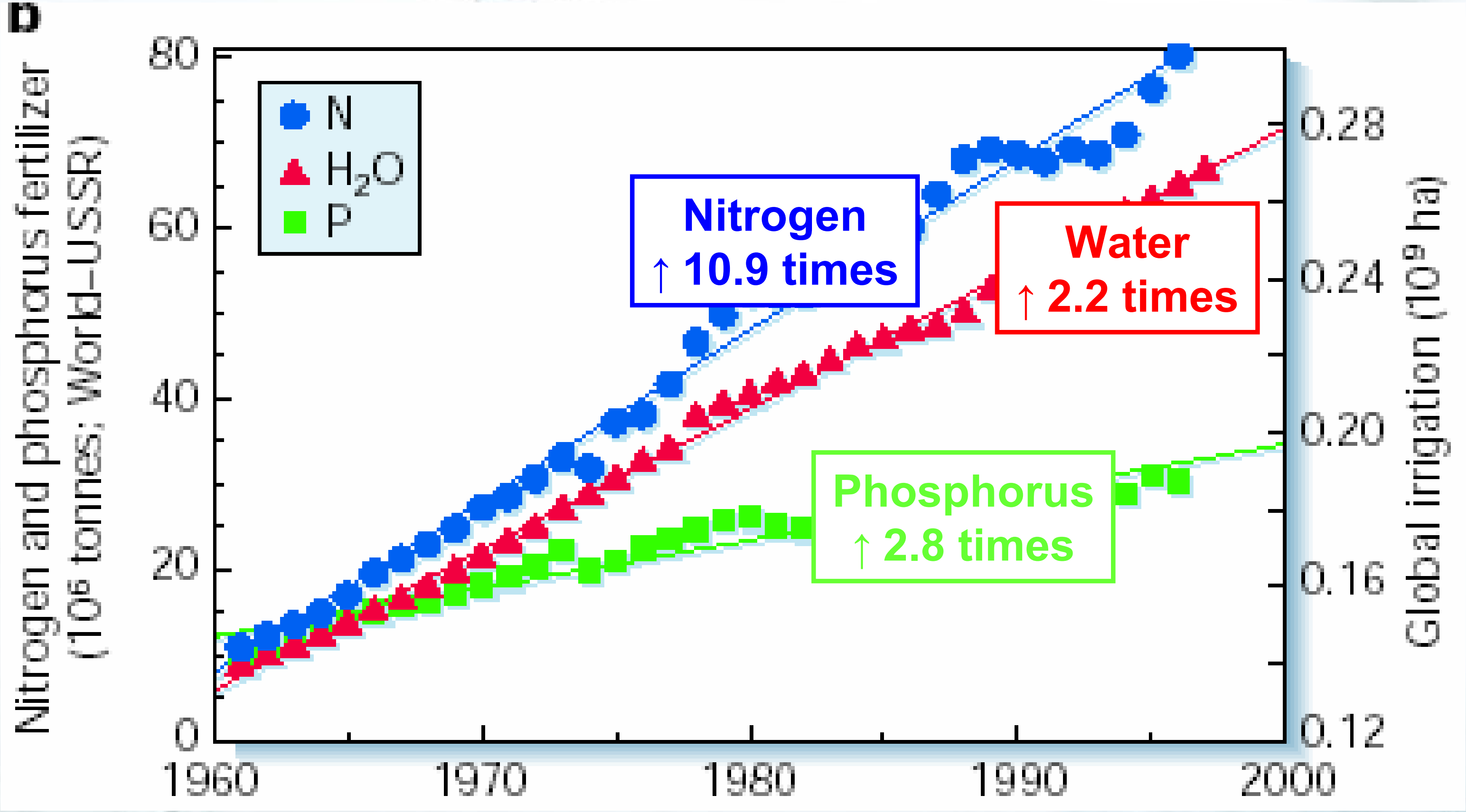
From Population Reference Bureau (2006) www.prb.org

Agriculture's response



From Tilman et al. (2002) Nature 418:671-677

Agriculture's response



From Tilman et al. (2002) Nature 418:671-677

Unintended consequences

http://www.ers.usda.gov/amberwaves/September04/images/soil-erosion5.jpg

la era del ecoprogreso
XVII CONGRESO AAPRESID

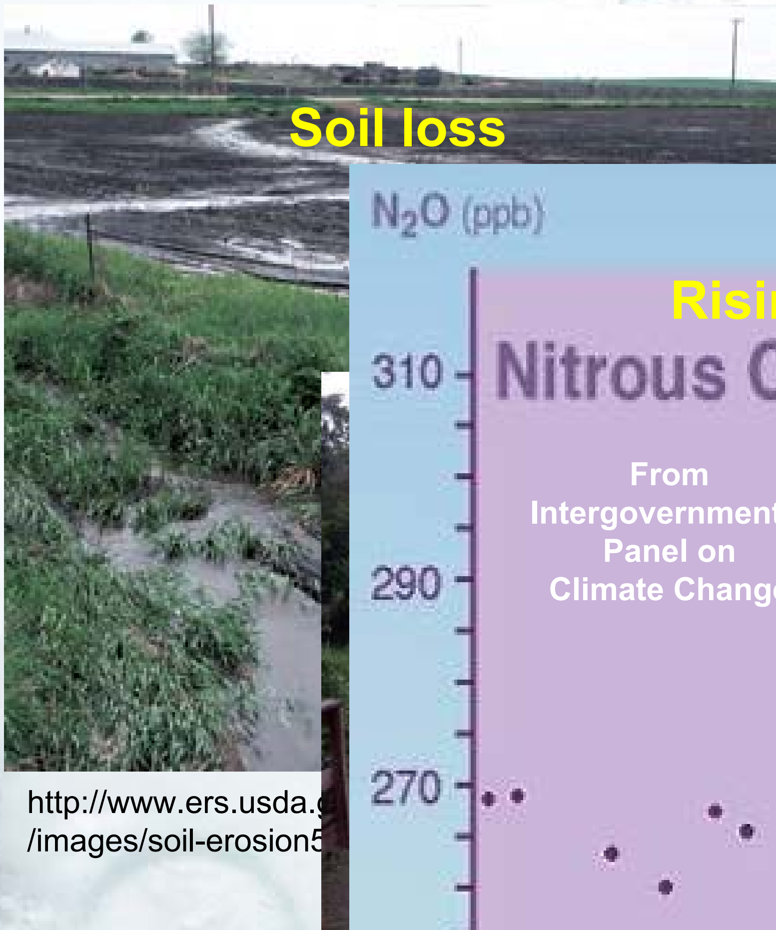
Unintended consequences

http://www.ers.usda.g
/images/soil-erosion5

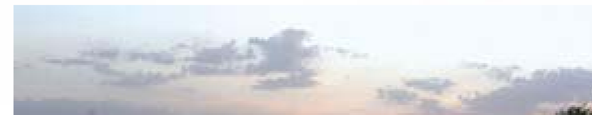
http://www.okstate.edu/artsci/botany/bisc3034/lnotes/images
/EUTROPHICATION02.JPG

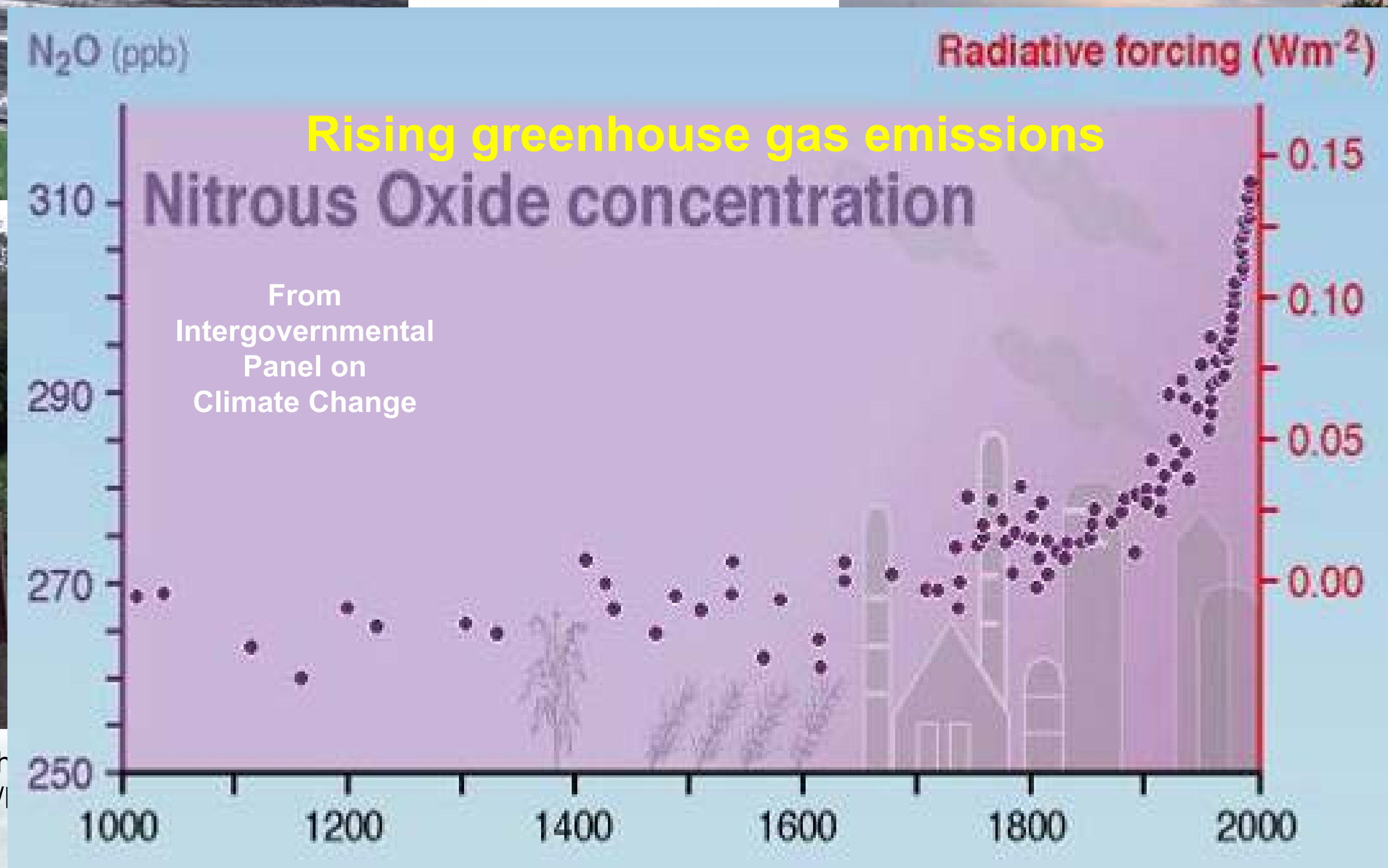
http://media-2.web.britannica.com/eb-media/52/90452-004-15A17E1E.jpg

Unintended consequences



http://www.ers.usda.g
/images/soil-erosion5

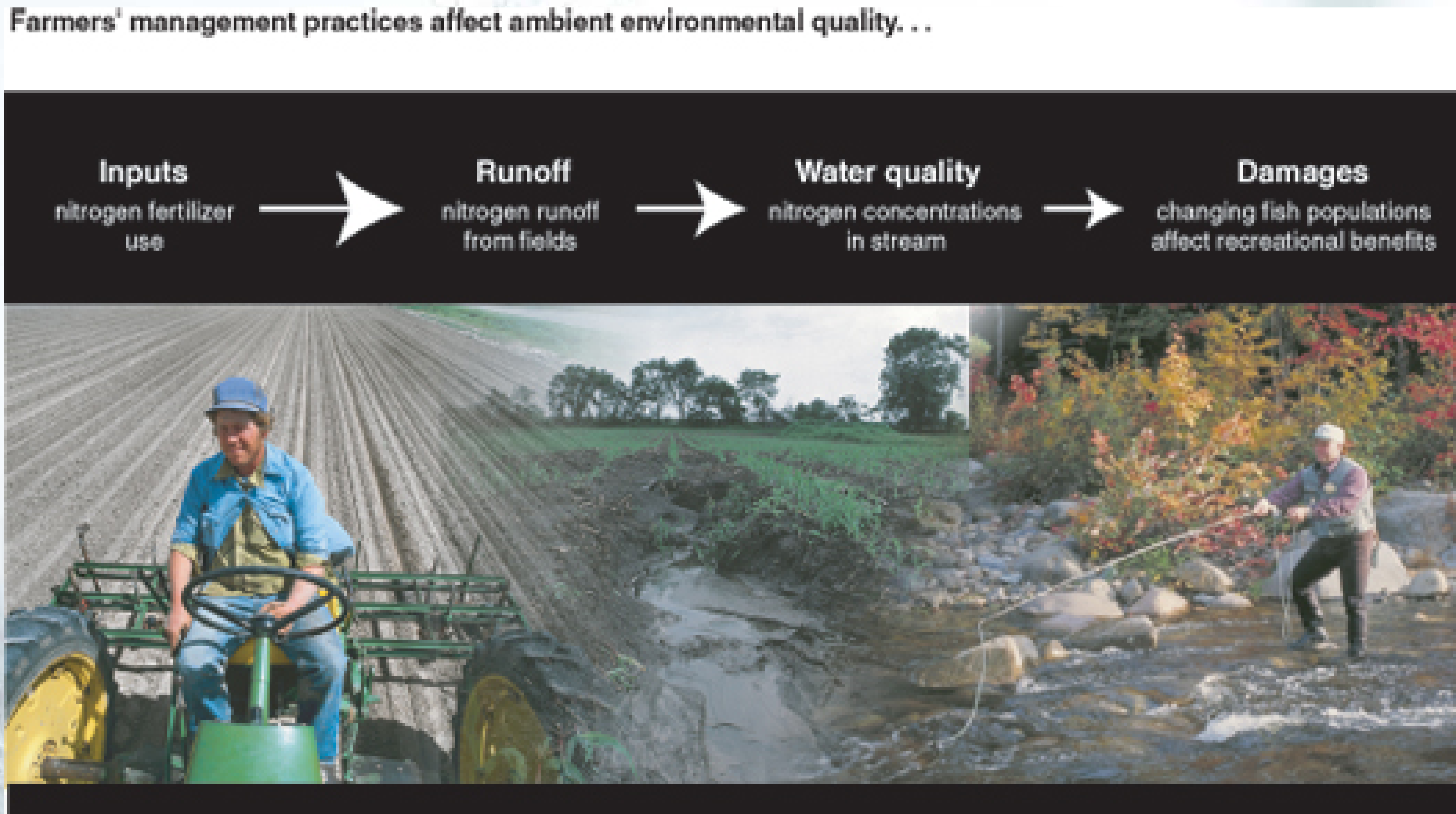




h
/I

la era del ecoprogreso
XVII CONGRESO AAPRESID

Unintended consequences



http://www.ers.usda.gov/amberwaves/september04/features/charts/measuringsuccess_1.jpg

Scars on the landscape

http
publish

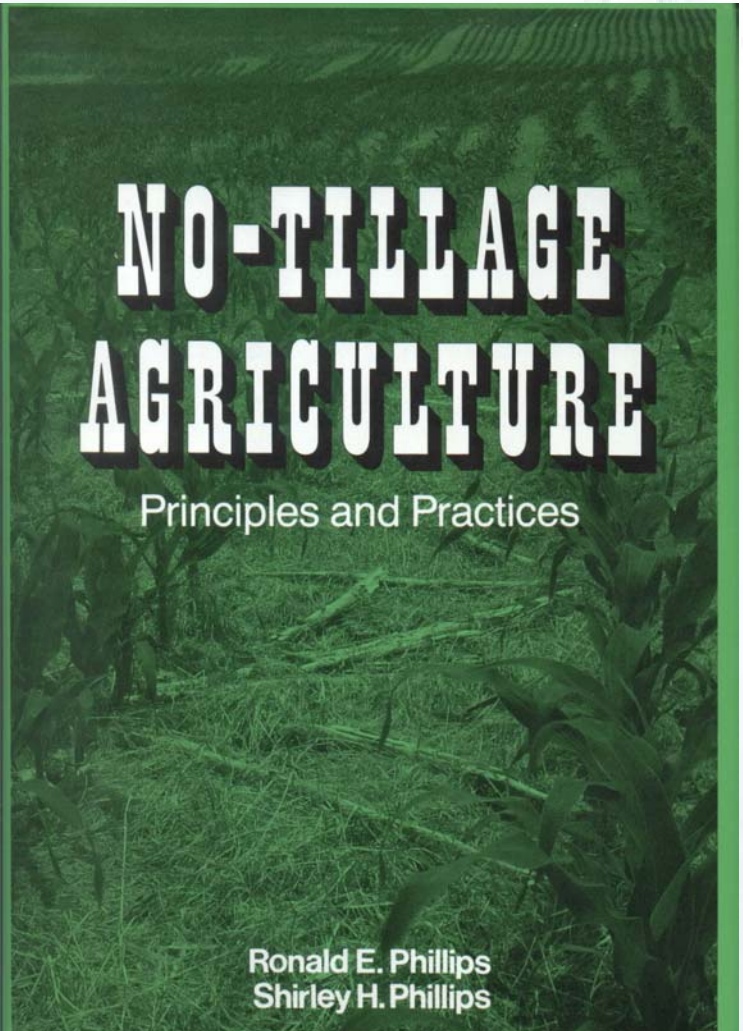
cgiar.org/images/
gif

http://www.wmo.
news/archive/ima

http://www.okcc.state.ok.us/Home/stewardship/dust-bowl_photo.jpg

Conservation agricultural systems

…developed to preserve soil and its beneficial properties



1984, Van Nostrand Reinhold Co.

"No-tillage cropping systems and concepts have evolved rapidly since the early 1960s and are attracting attention worldwide."

"The rapid growth and interest is associated with increasing pressures for food production from a fixed land resource base with degrading effects of erosion, soil compaction and other factors becoming more noticeable."

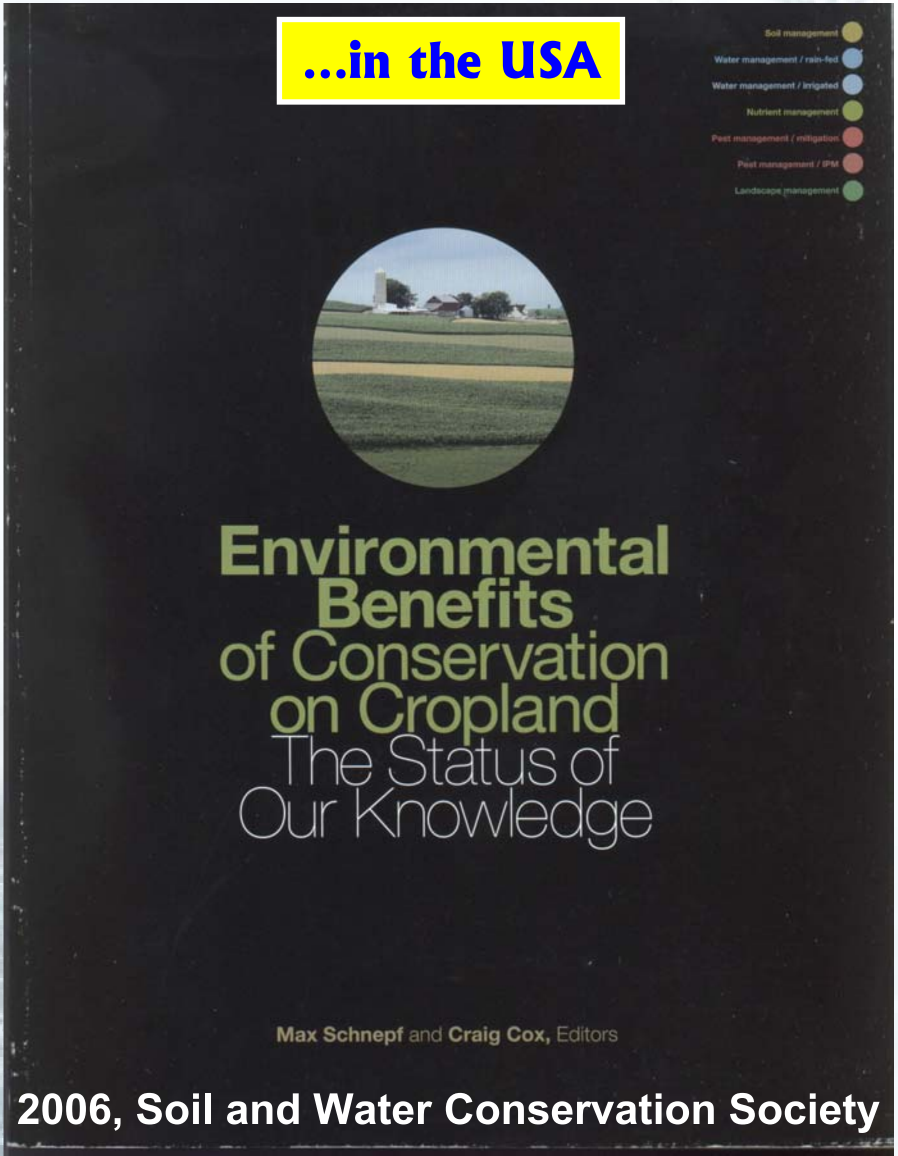
"The start of the 21st century may signal the end of a period of 200 years in developing the plow…"

"No-tillage will doubtless continue to be one of the most important of these production practices, one that protects the soil, conserves water and reduces energy consumption."

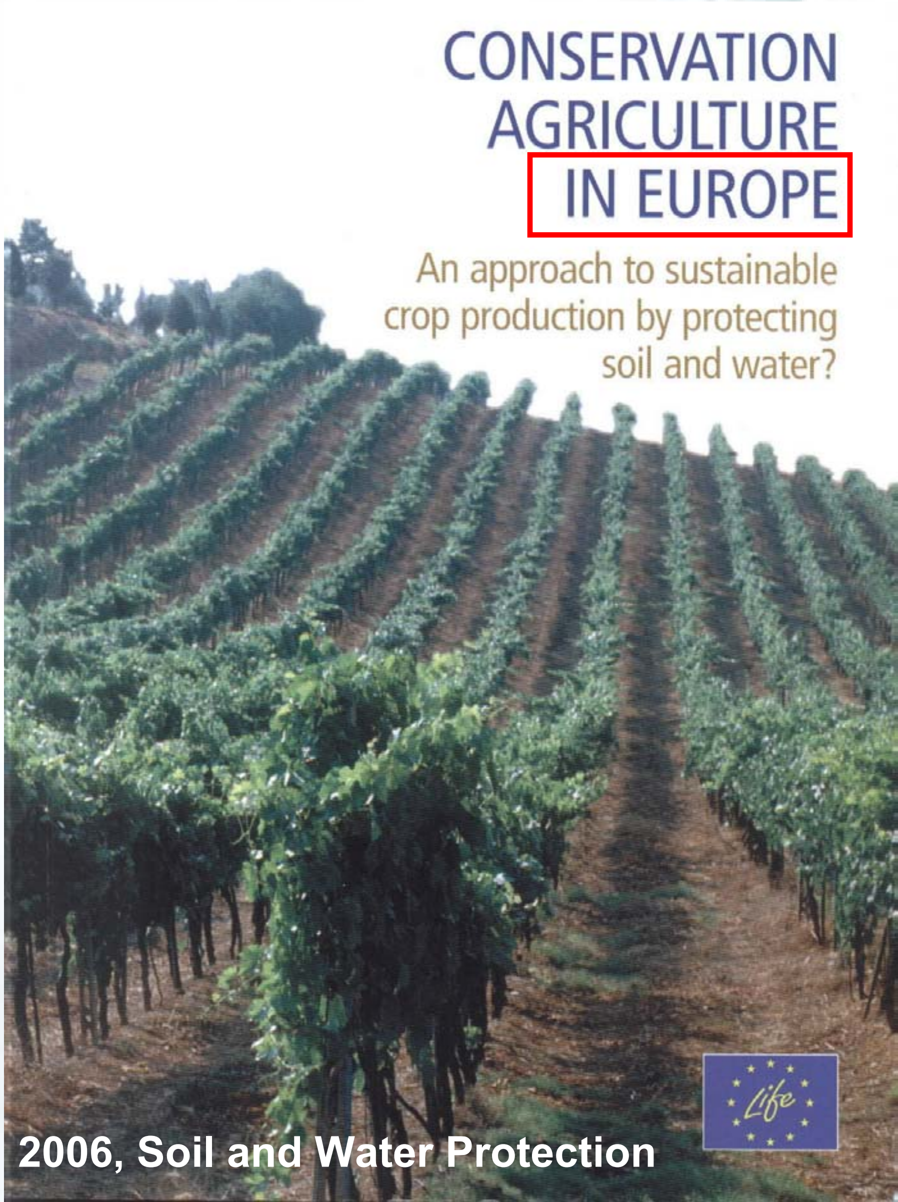
la era del ecoprogreso
XVII CONGRESO AAPRESID

Information resources

...in the USA



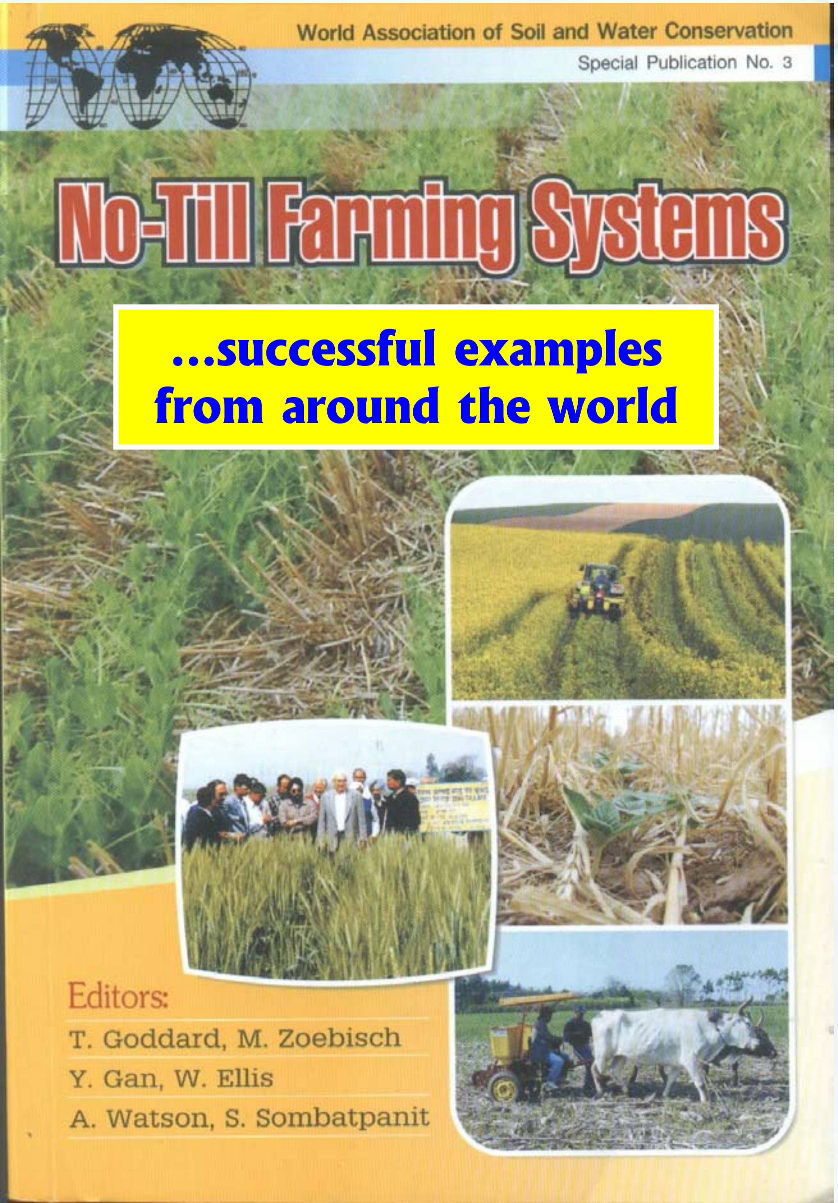
2006, Soil and Water Conservation Society



2006, Soil and Water Protection

la era del ecoprogreso
XVII CONGRESO AAPRESID

Information resources

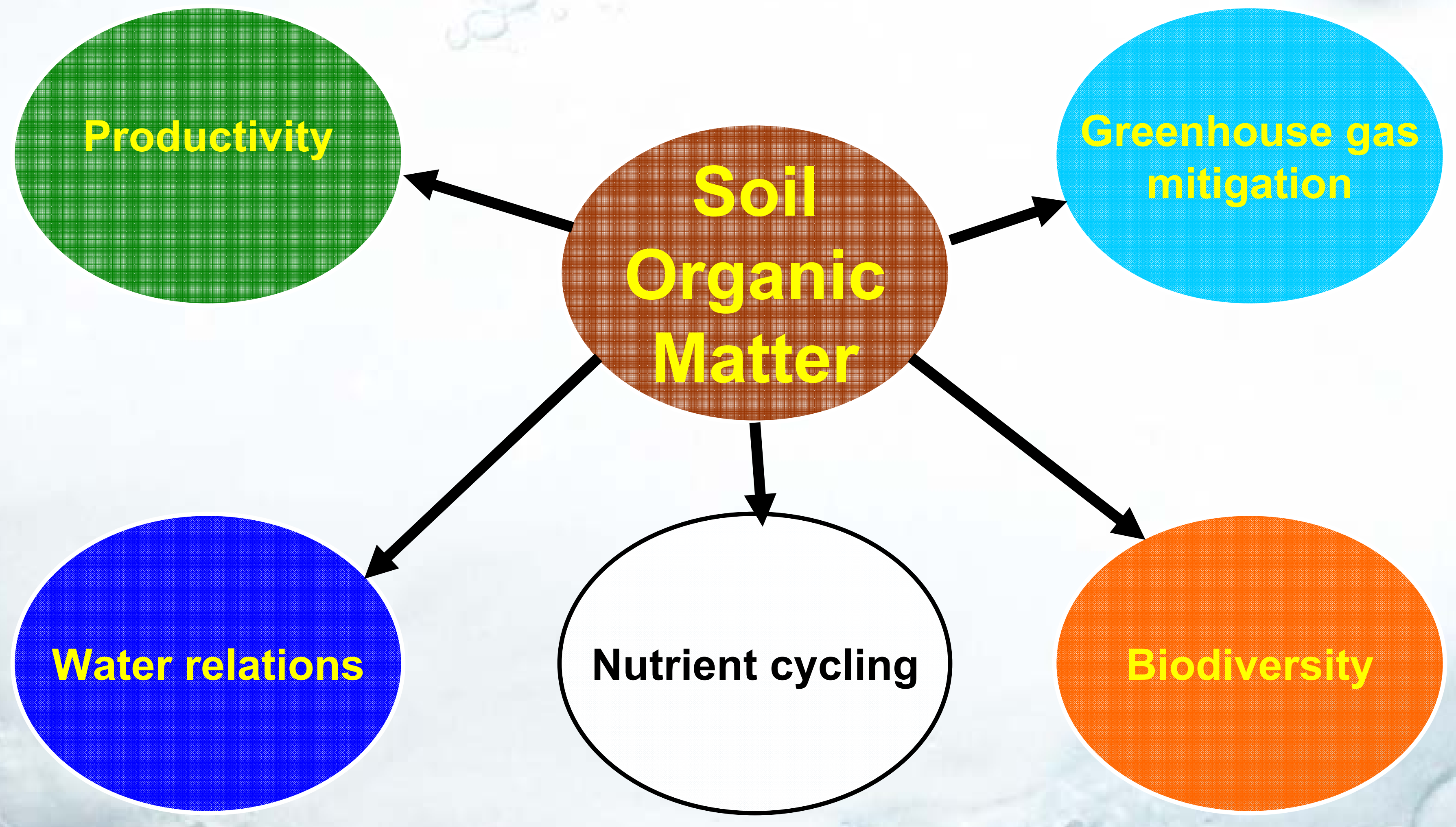


...successful examples from around the world

Enhancing resource efficiency by combining conservation cropping with livestock production

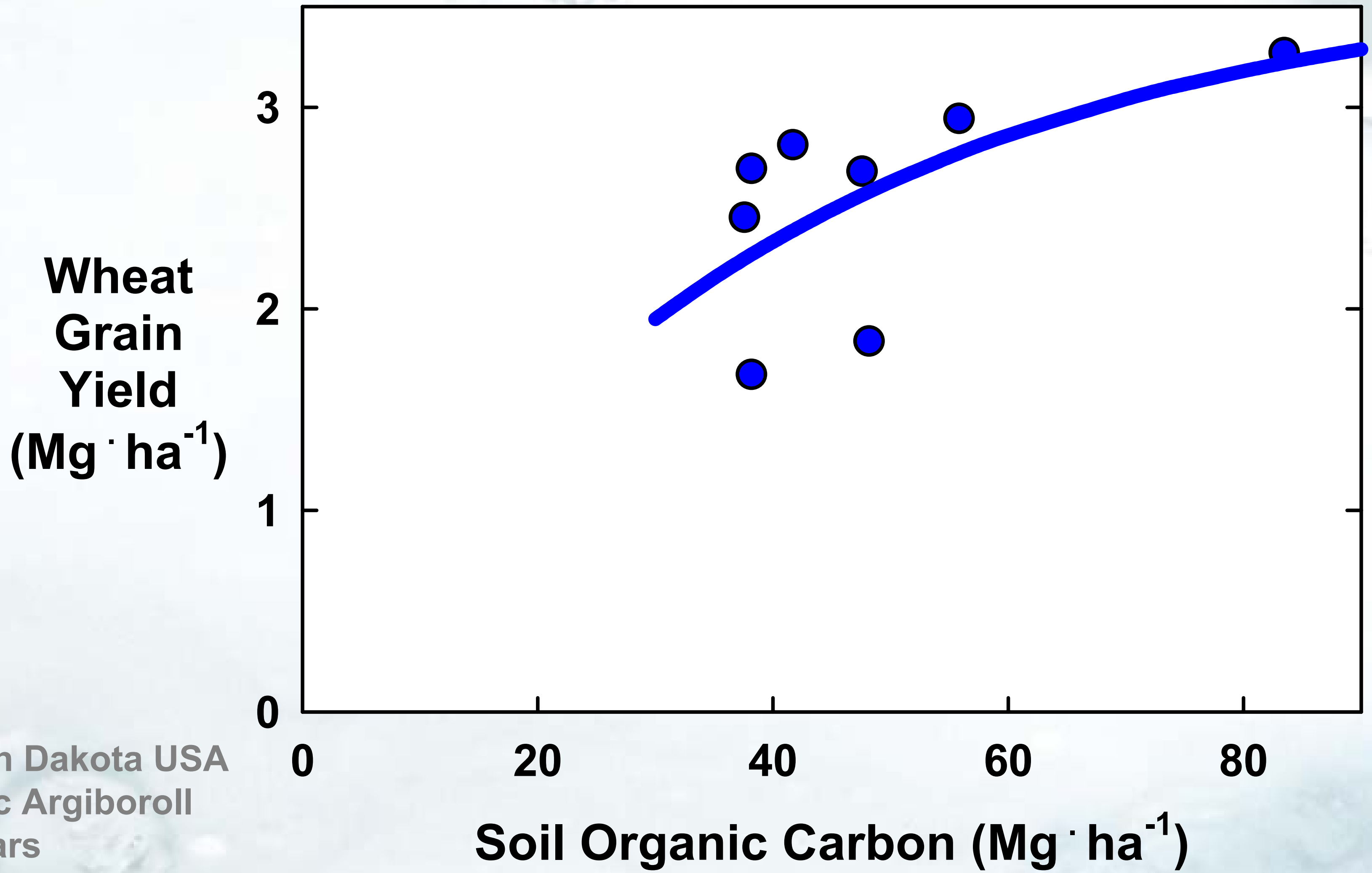
2007, Food and Agriculture Organization

Soil organic matter as an indicator of ecosystem services



la era del ecoprogreso
XVII CONGRESO AAPRESID

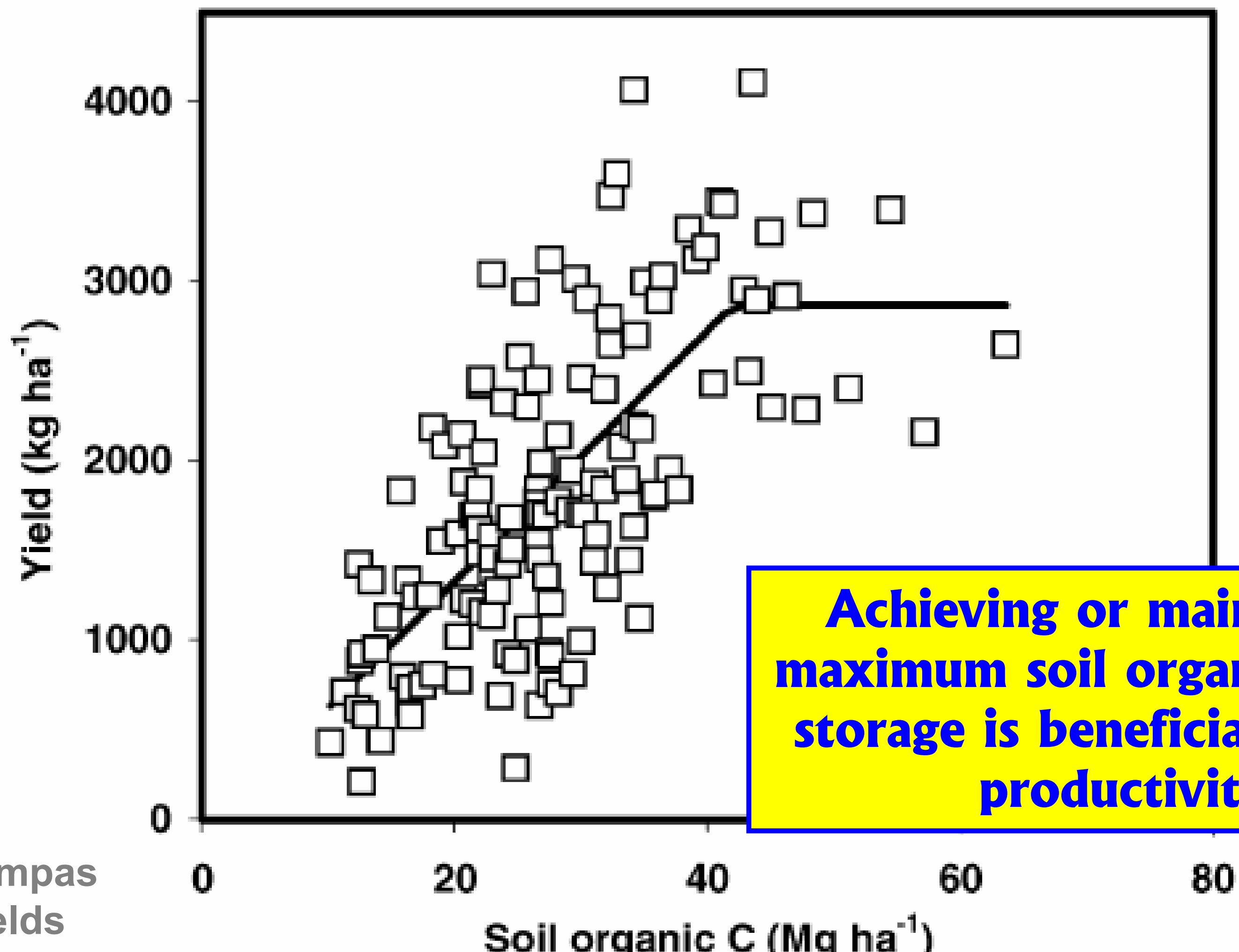
Effect of soil organic matter on crop productivity



North Dakota USA
Typic Argiboroll
3 years
Water controlled
0-30 cm depth

Data from Bauer and Black (1994) Soil Sci. Soc. Am. J. 58:185-193

Effect of soil organic matter on crop productivity

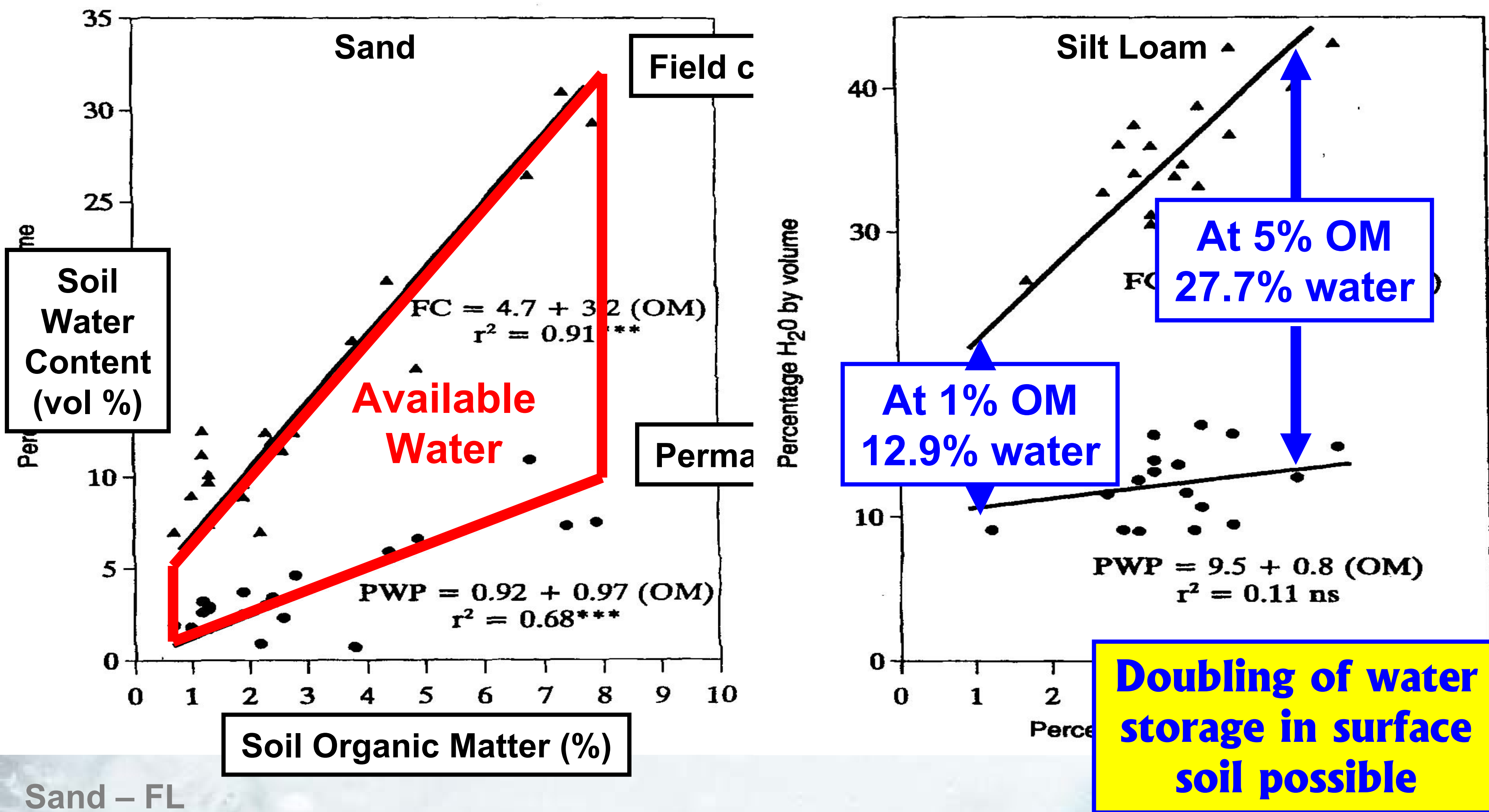


Achieving or maintaining maximum soil organic matter storage is beneficial to crop productivity

Argentine Pampas
134 farmer fields
Udolls, Ustolls, Psamments
3 years
0-20 cm depth

From Diaz-Zorita (1999) Agron. J. 91:276-279

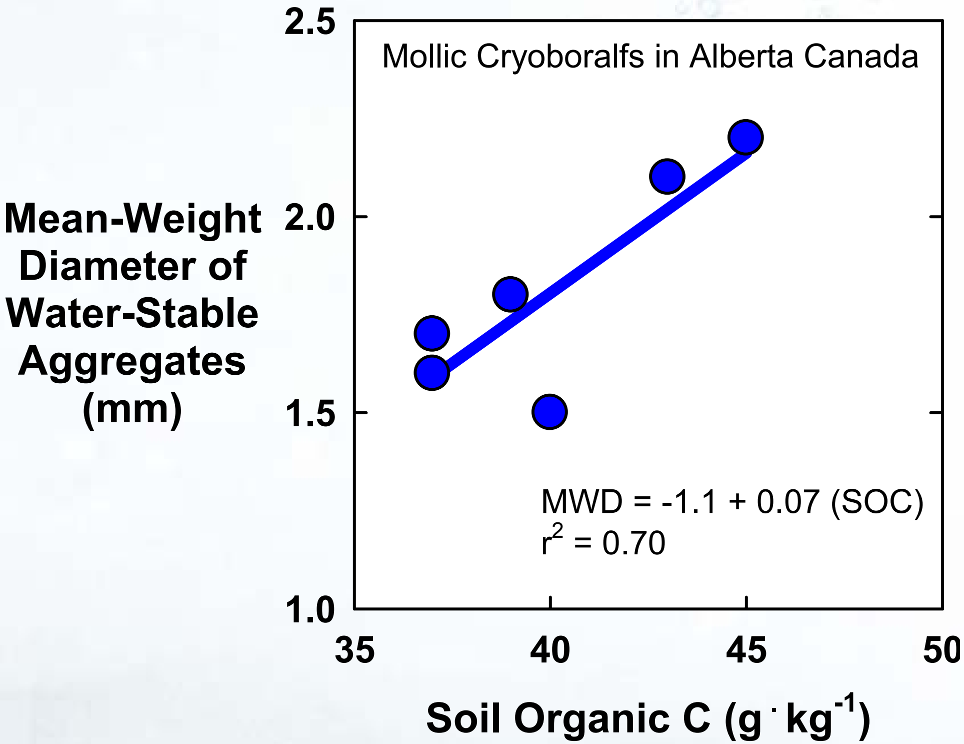
Effect of soil organic matter on water retention

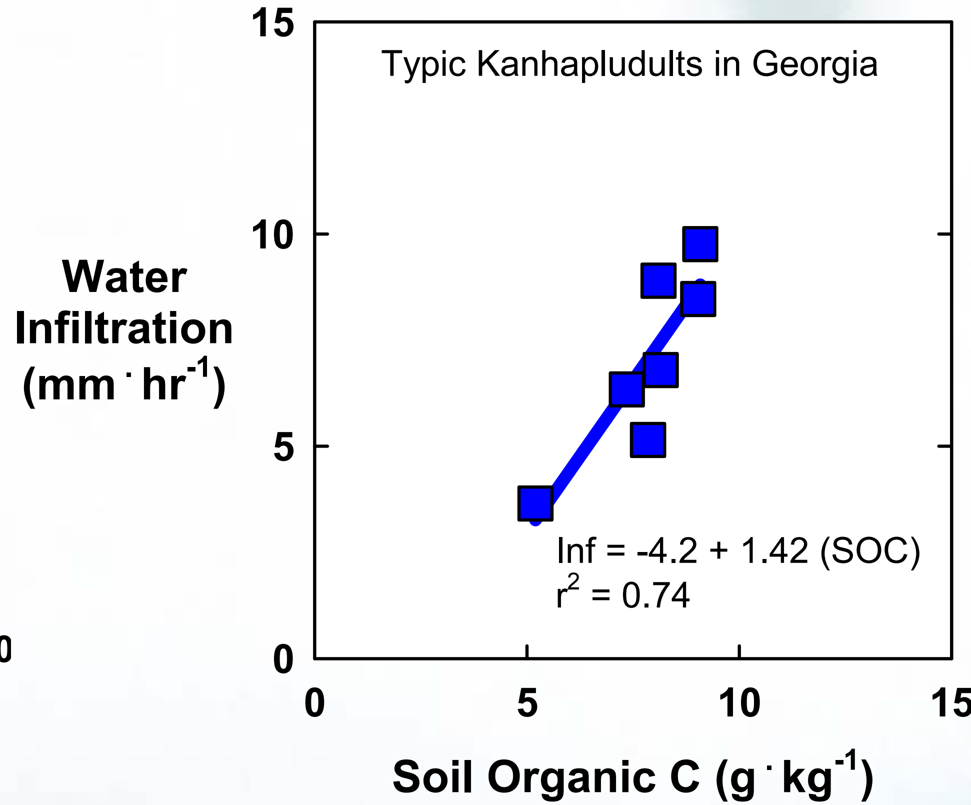


Sand – FL
Silt Loam – IA, WI, MN, KS
Surface soils only

From Hudson (1994) J. Soil Water Conserv. 49:189-194

Effect of soil organic matter on water-related surface-soil properties



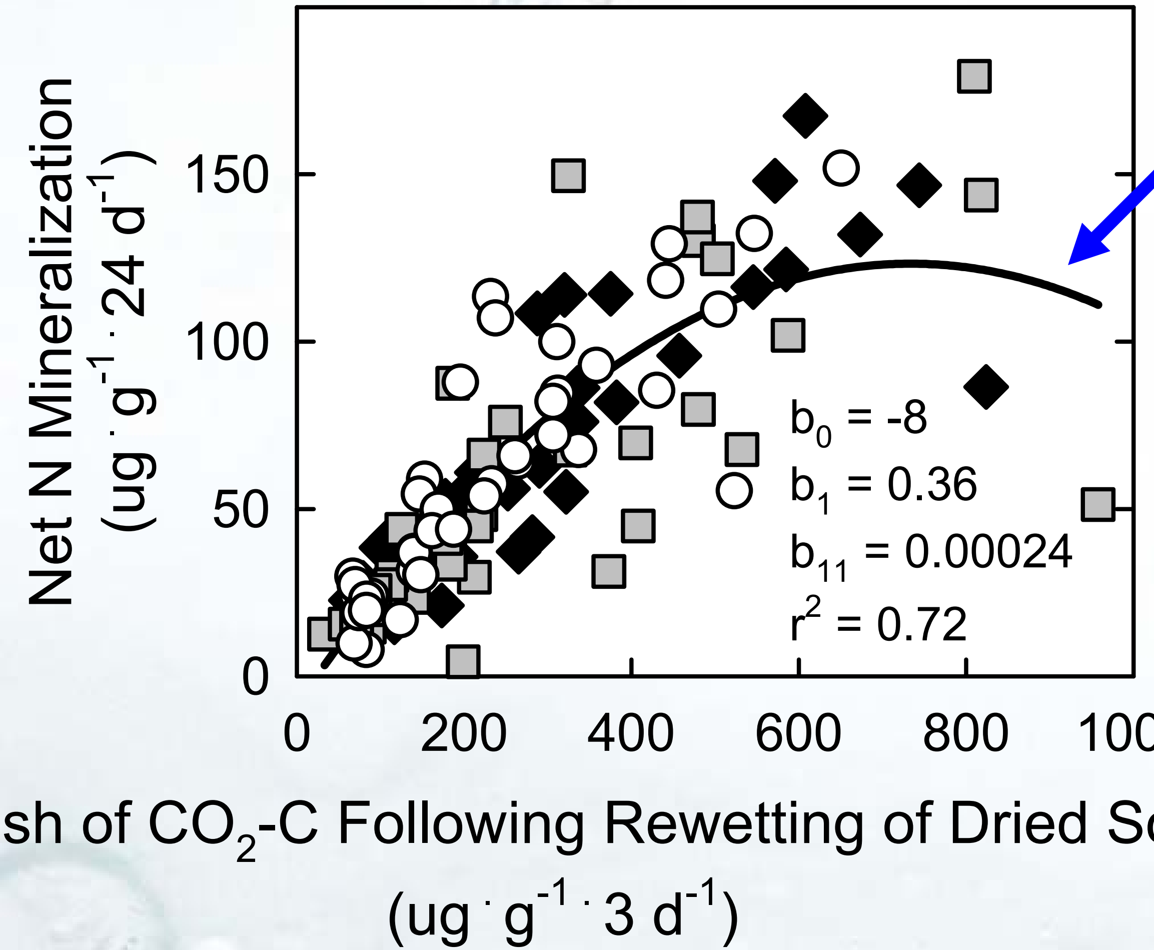


Soil organic matter improves surface conditions to get more water into soil

Data from Arshad et al. (2004) Soil Till. Res. 77:15-23
Carreker et al. (1977) USDA-ARS S-160

la era del ecoprogreso
XVII CONGRESO AAPRESID

Effect of soil organic matter on nutrient cycling



Immobilization can occur with excessively high carbon

A steady supply of inorganic nitrogen is available from the decomposition of easily decomposed organic matter

Franzluebbers and Brock (2007) Soil Till. Res. 93:126-137

Effect of soil organic matter on greenhouse gases

Carbon dioxide (CO_2)

Storage of carbon in soil reduces net CO_2 emission to the atmosphere

Nitrous oxide (N_2O)

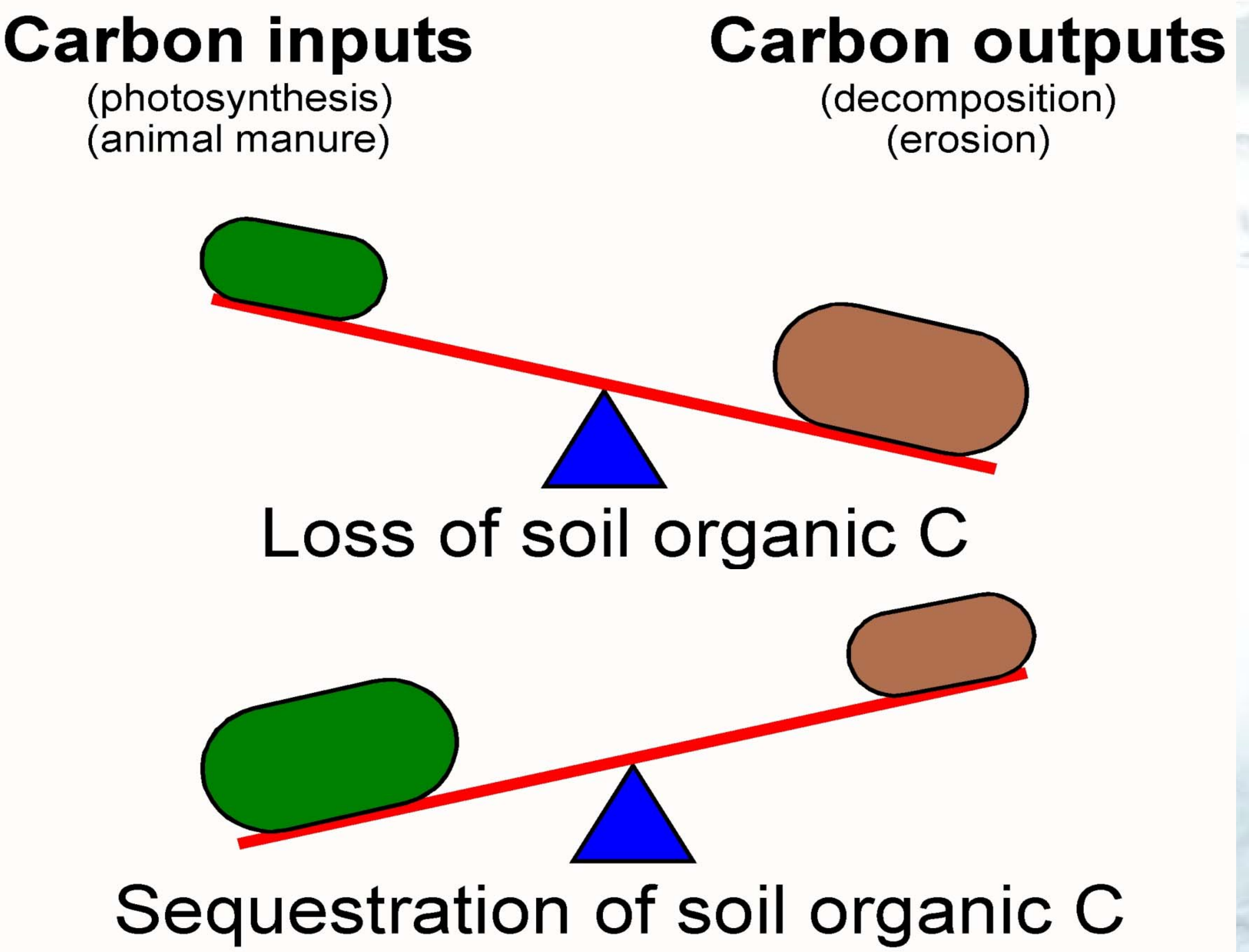
Water-soluble organic C, nitrate (NO_3), and low oxygen are prerequisites for denitrification

Methane (CH_4)

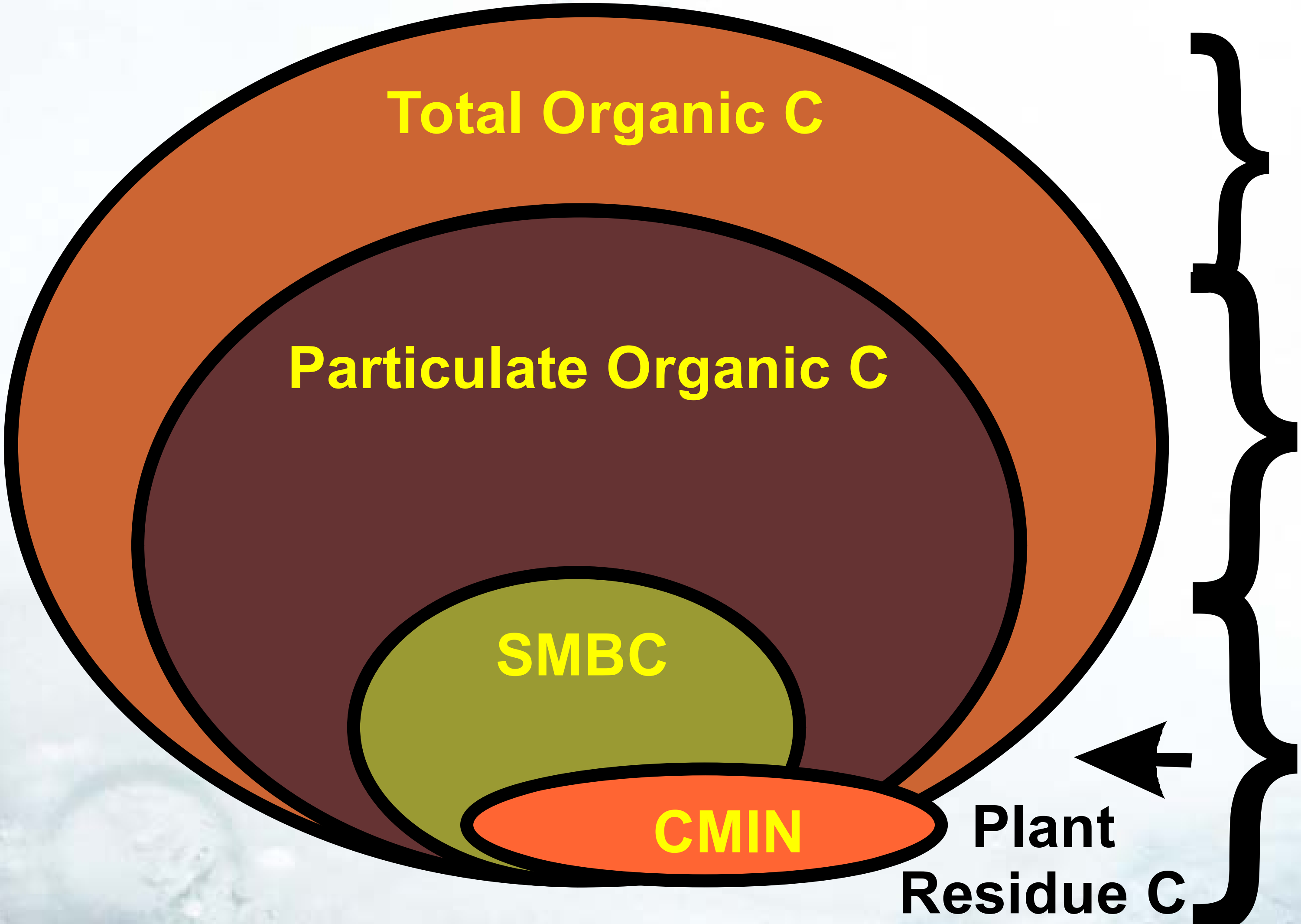
Soils with high surface soil organic matter are often a net sink for CH_4; but excessively wet soils will emit CH_4

How does management change soil organic matter?

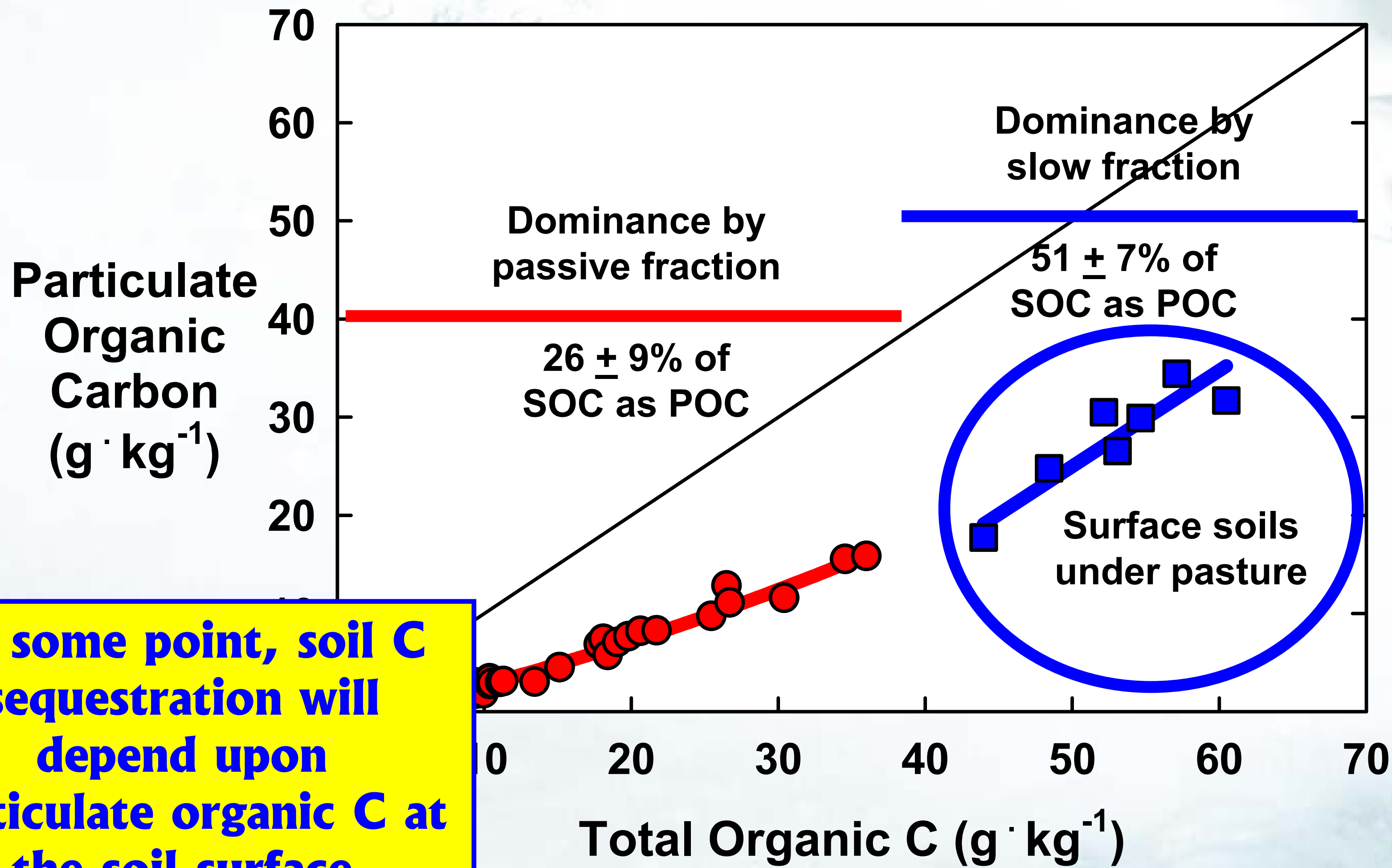
Quantifying soil organic carbon in agricultural systems



Fractions of soil organic C



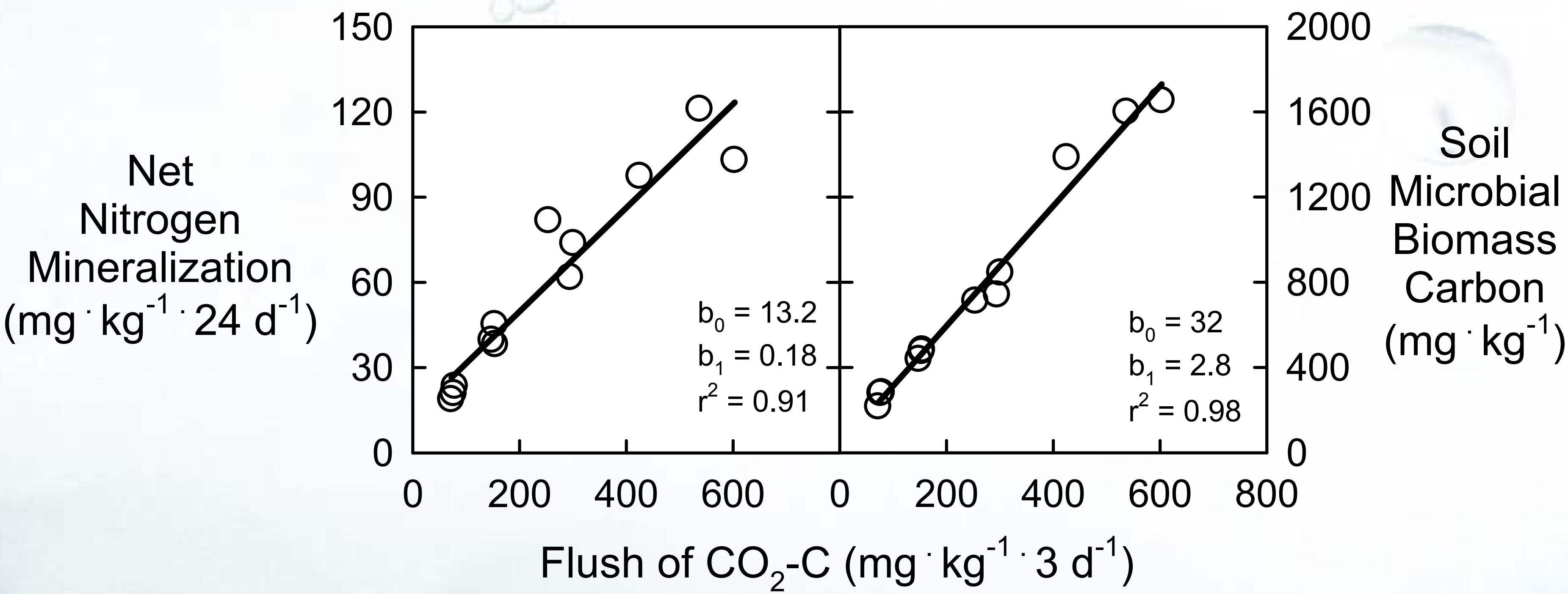
Slow fraction of soil organic C



At some point, soil C sequestration will depend upon particulate organic C at the soil surface

Franzluebbers and Stuedemann (2002) Environ. Poll. 116:S53-S62

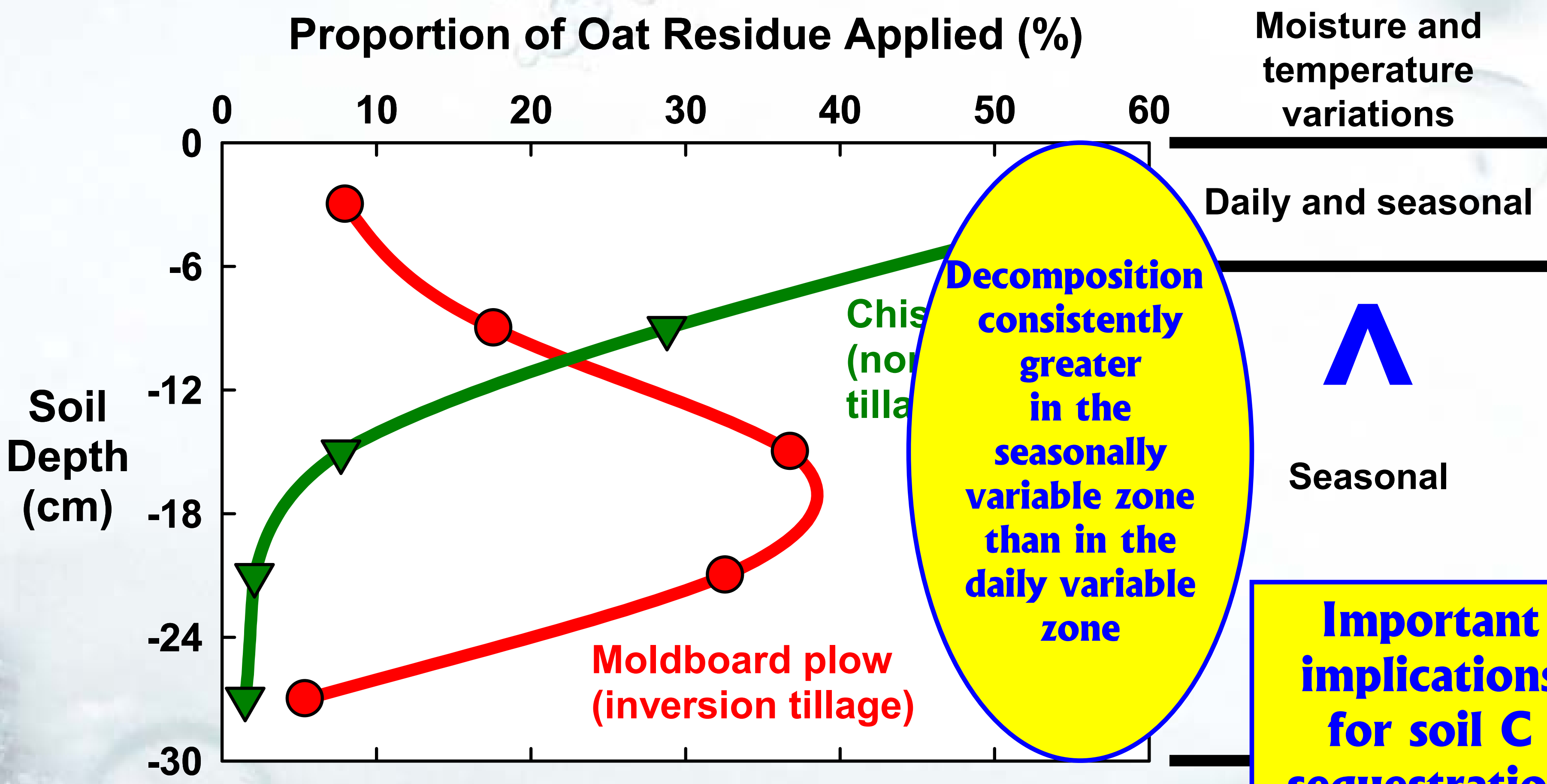
Active fraction of soil organic C



The relatively simple, rapid, and reliable methodology makes the flush of CO_2 a viable tool for testing of biologically active organic matter.

Franzluebbers and Haney (2006) Proc. 17th ISTRO, Kiel, Germany

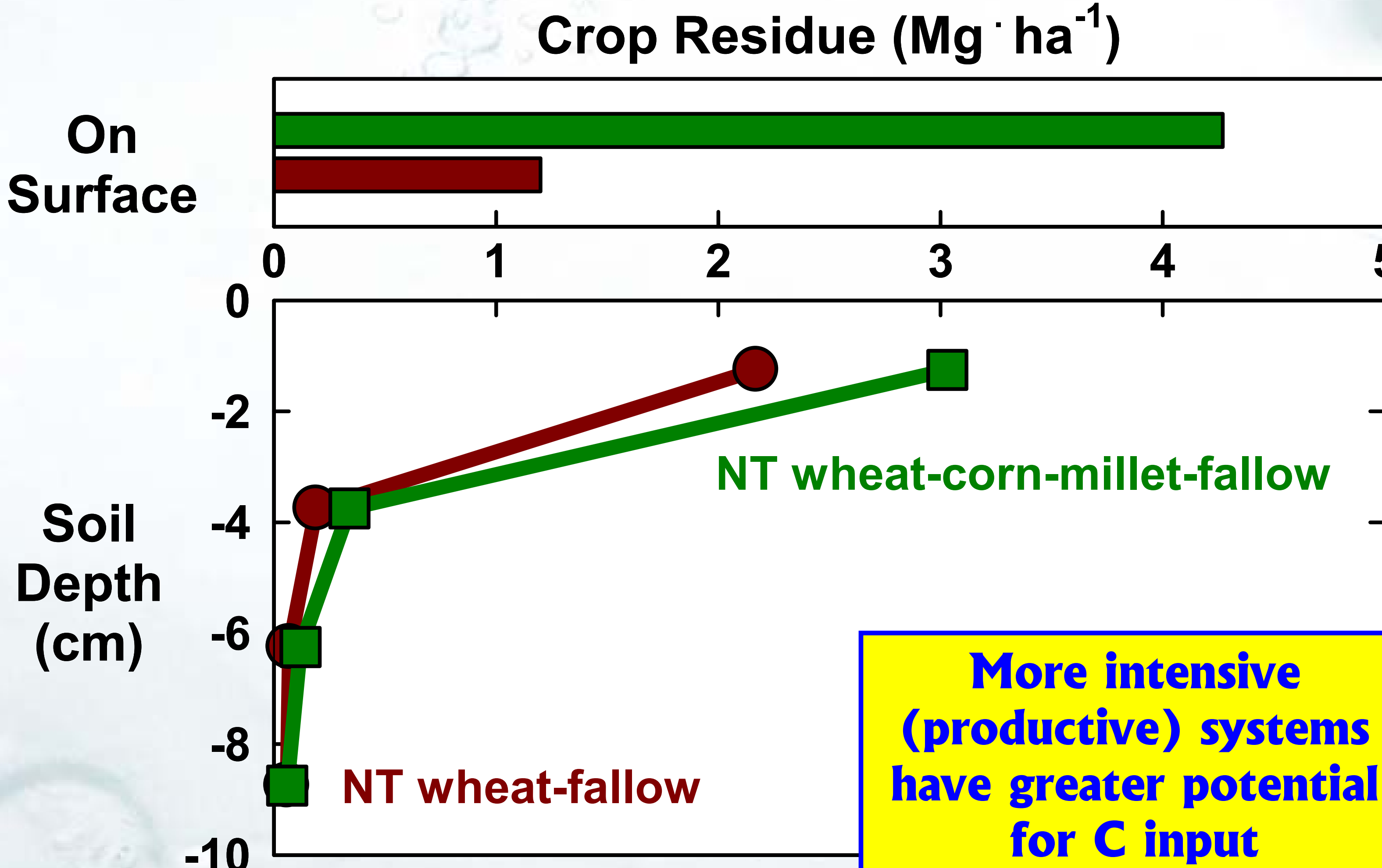
Tillage influence on residue distribution (C input) in soil



Important implications for soil C sequestration

Data from Allmaras et al. (1996) Soil Sci. Soc. Am. J. 60:1209-1216

Residue distribution (C input) without tillage



More intensive (productive) systems have greater potential for C input

At the end of 8 years of management

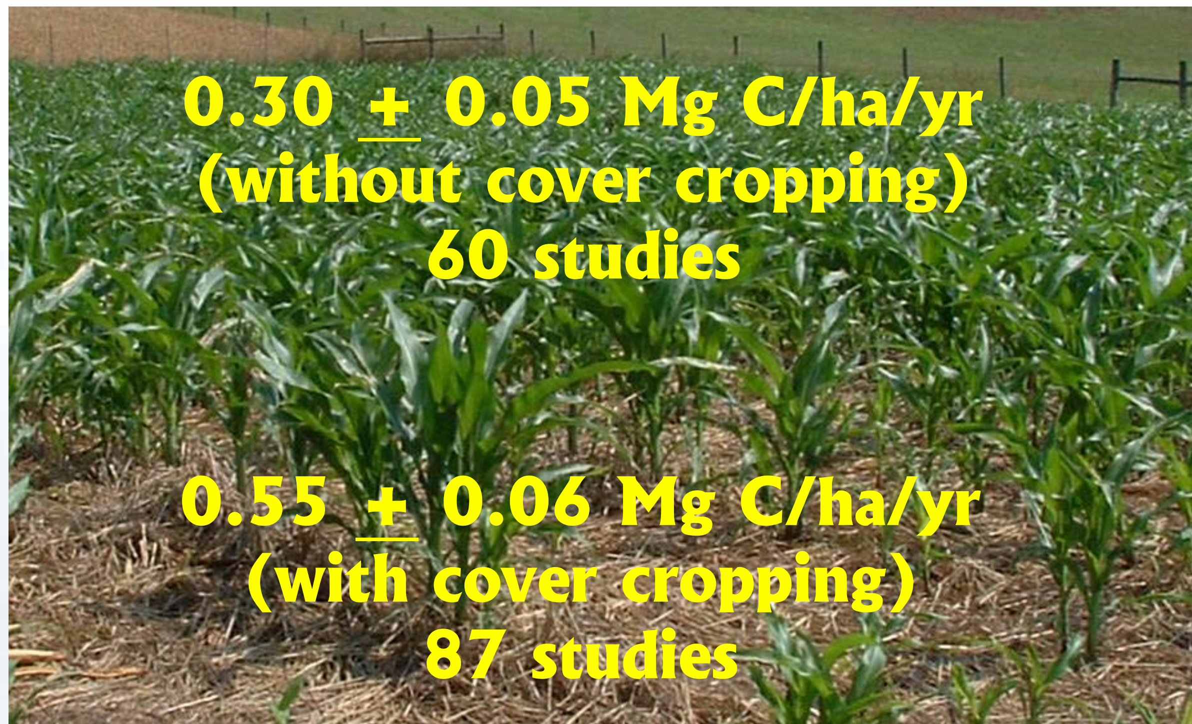
Data from Ortega et al. (2002) Agron. J. 94:944-954

la era del ecoprogreso
XVII CONGRESO AAPRESID

Cover crop effect on soil organic C accumulation

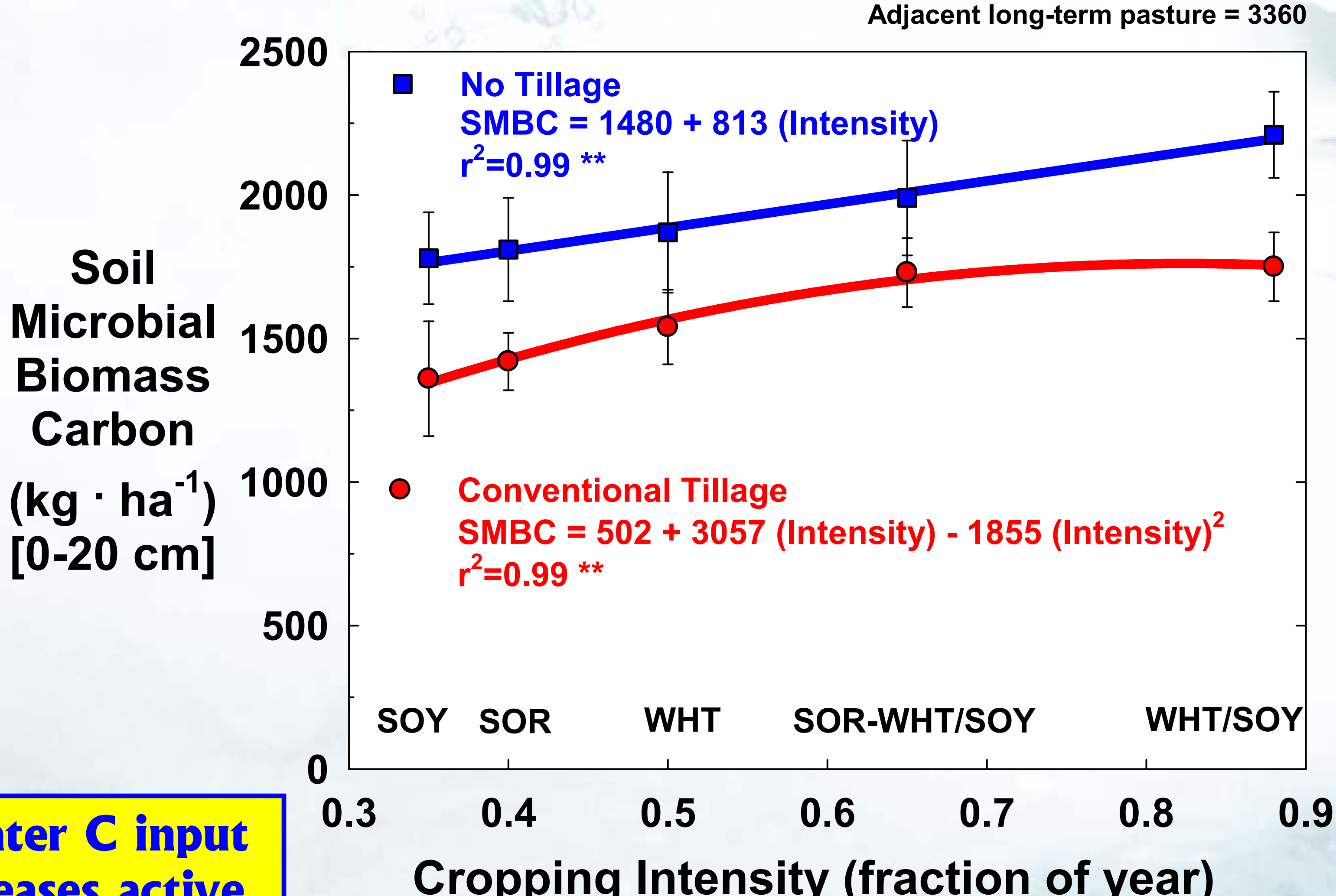
Photos of 2 no-tillage systems in Virginia USA

Soil Organic Carbon Sequestration in the Southeastern USA



Franzluebbers (2009) Soil Sci. Soc. Am. J. (in press)

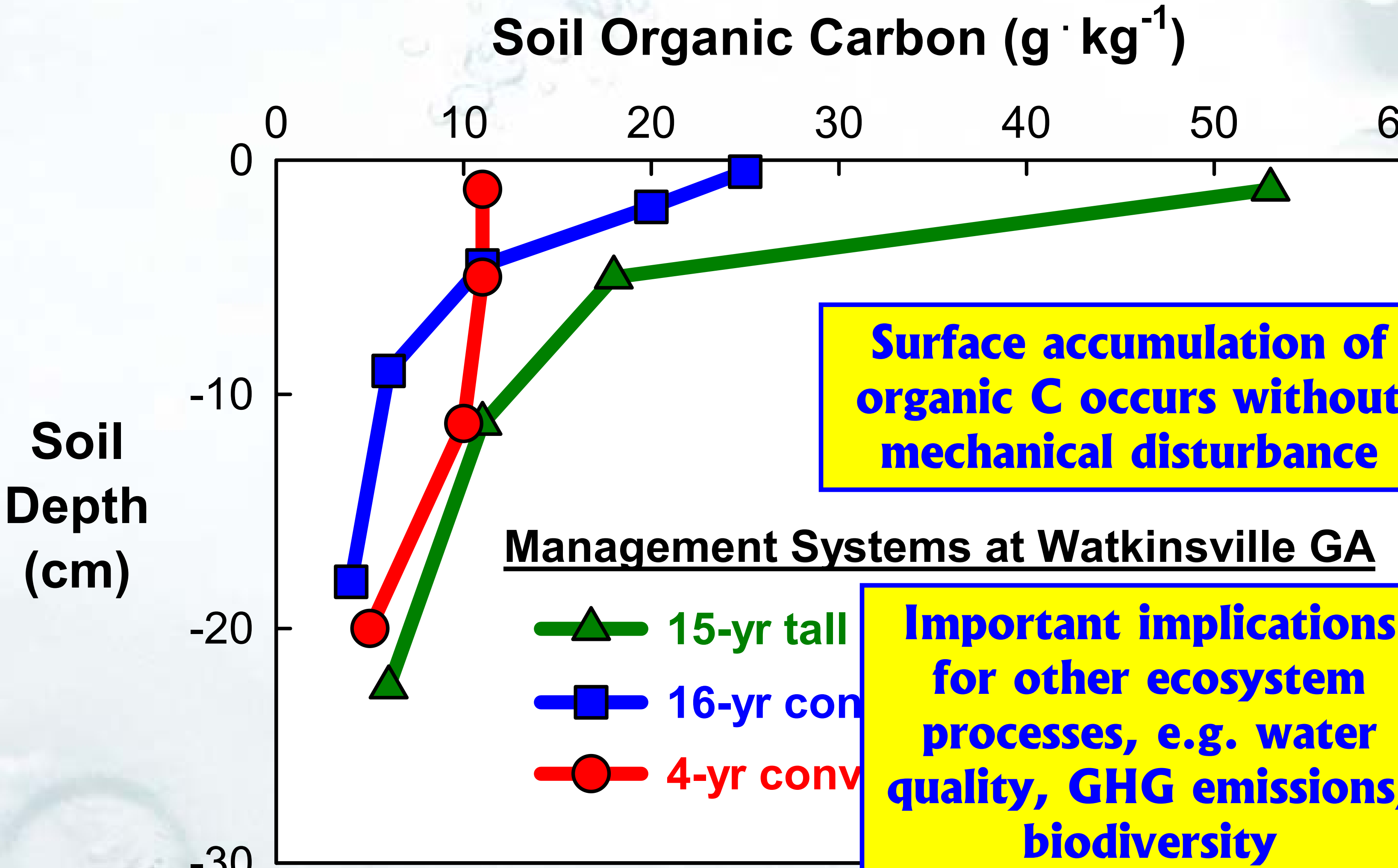
Cropping intensity effect on soil microbial biomass C



Greater C input increases active C fractions

Franzluebbers et al. (1998) Soil Till. Res. 47:303-308

Depth distribution of soil organic C

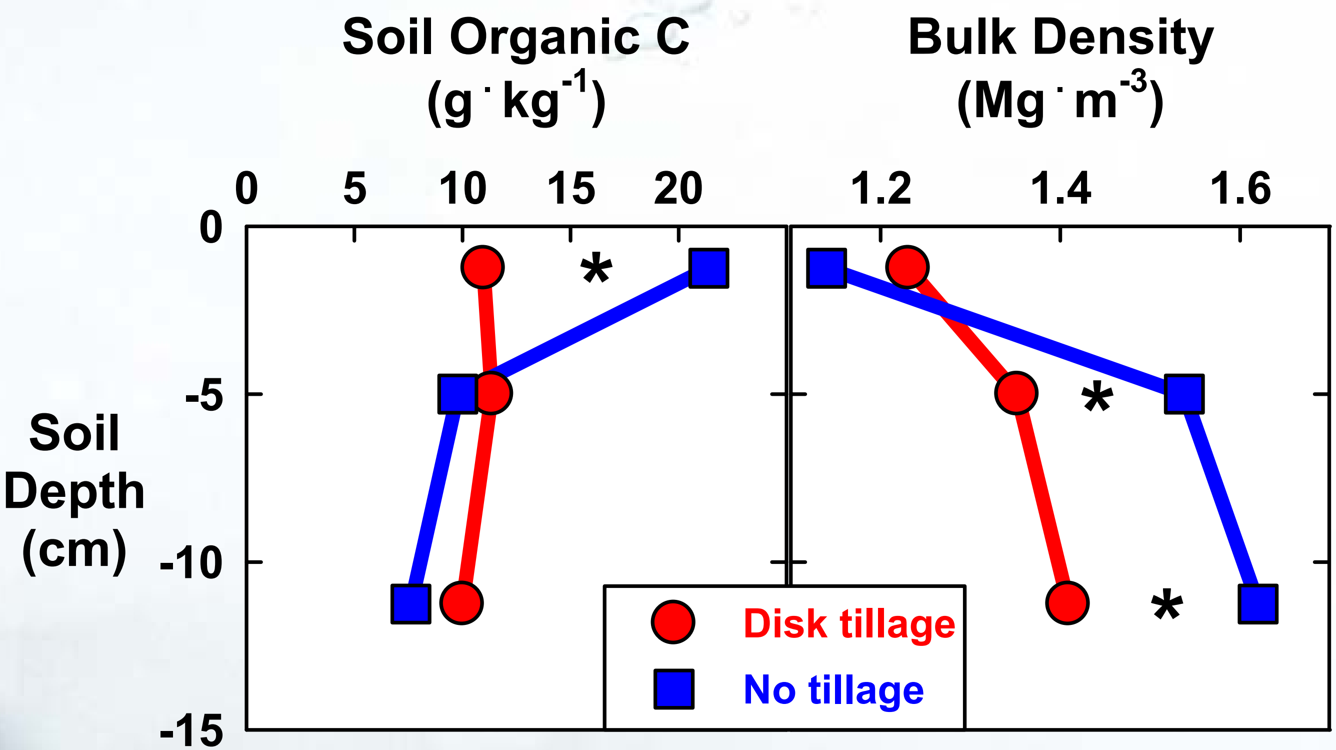


Surface accumulation of organic C occurs without mechanical disturbance

Important implications for other ecosystem processes, e.g. water quality, GHG emissions, biodiversity

From Schnabel et al. (2001) Ch. 12, Pot. U.S. Grazing Lands Sequester C, Lewis Publ.

Depth distribution and stock of plow-layer soil organic C

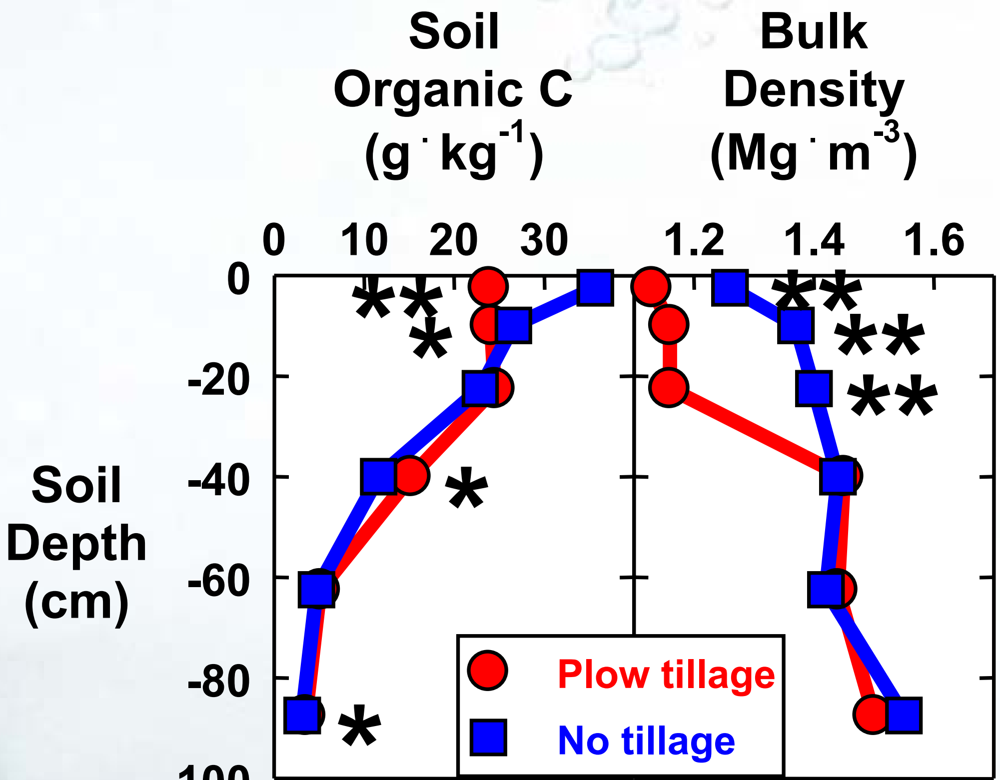


Carbon Content (Mg · ha-1)	DT		NT
	0.1	*	4.3
	3.3	*	5.9
	7.5		7.4
	10.3		8.9
Soil (0-15 cm)	21.1		22.2
Soil + residue	21.2	*	26.5

Replicated experiment
Georgia – SCL
Typic Kanhapludult
4-yr study
Sorghum, soybean, cotton

Franzluebbers et al. (1999)
Soil Sci. Soc. Am. J. 63:349-355

Depth distribution and stock of soil-profile organic C



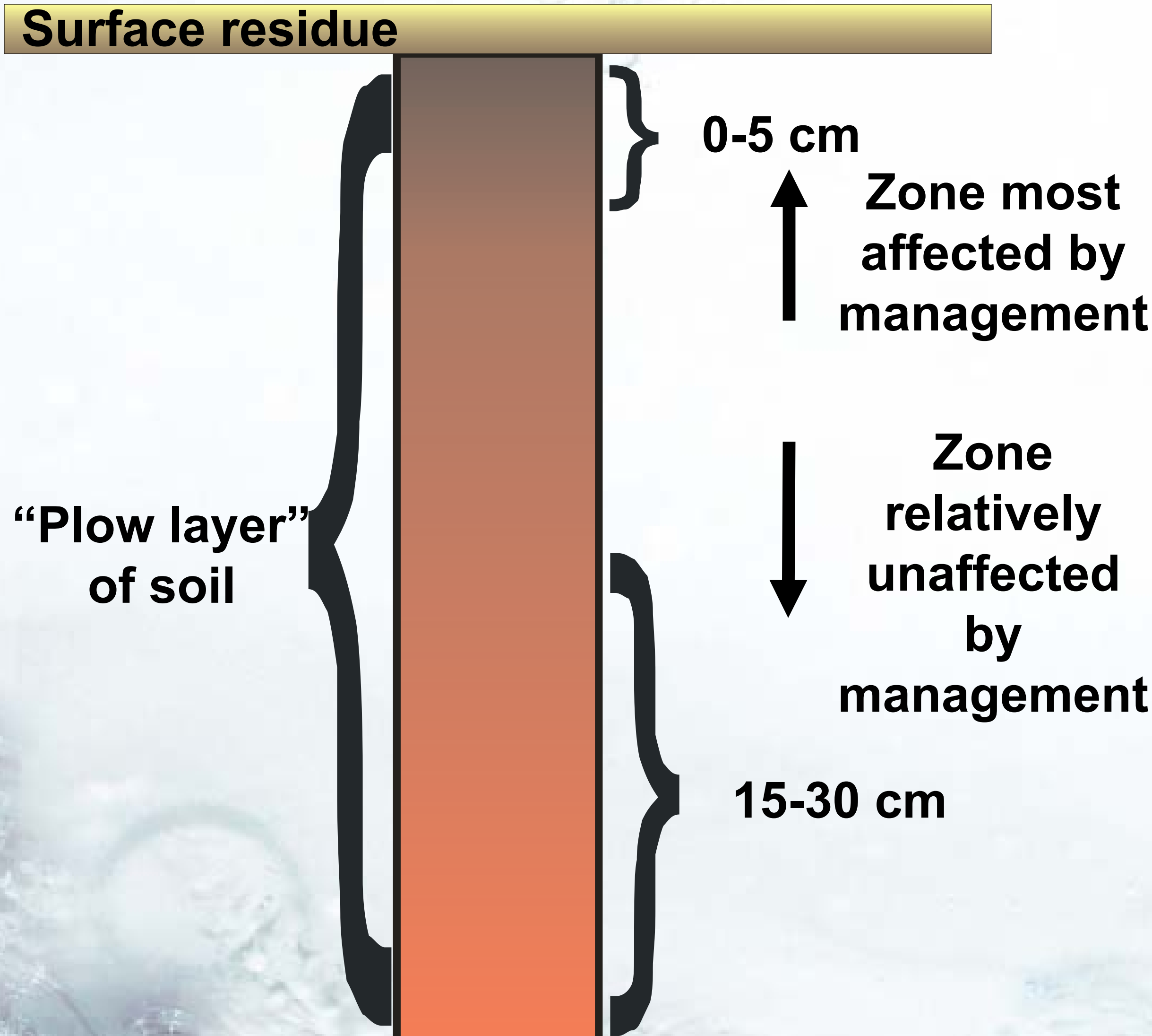
Carbon Content ($Mg \cdot ha^{-1}$) PT		Carbon Content ($Mg \cdot ha^{-1}$) NT	Cumulative Carbon Sequestration Rate (Mg/ha/yr)
13.6	<<	22.5	0.32
27.9	<<	36.4	0.62
42.8	<	48.2	0.81
43.9	>	33.3	0.44
18.2		16.7	0.38
12.8		12.2	0.36
Soil (0-30 cm) 84.1	<	107.0	
Soil (0-100 cm) 159.2	<	169.3	

Depth of sampling can be very important

Replicated experiment
Indiana – SiCL
Typic Haplaquoll
28-yr study
Corn and corn/soybean

Data from Gál et al. (2007) Soil Till. Res. 96:42-51

Stratification ratio of soil organic C



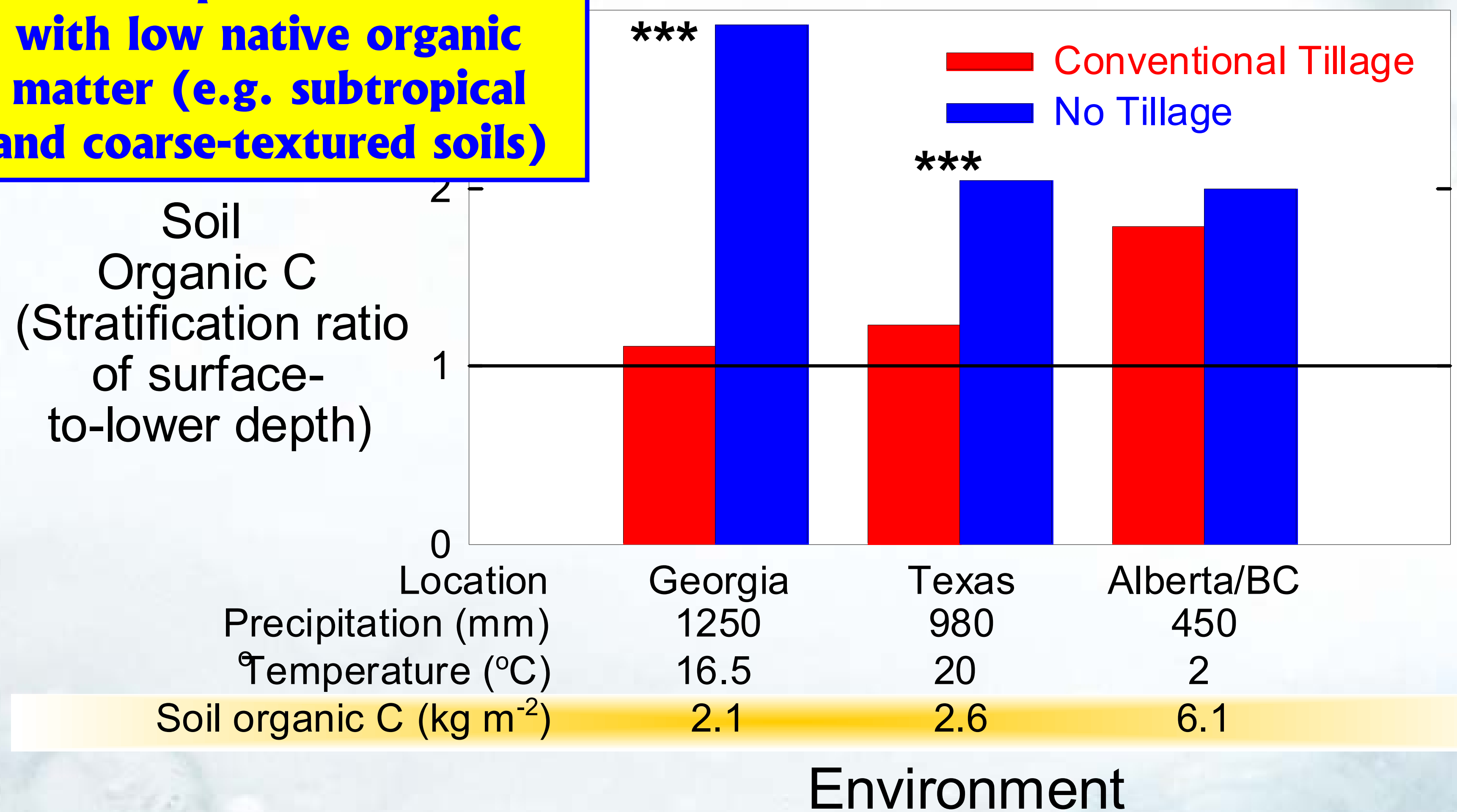
Stratification Ratio

$$\frac{\text{SOC (0-5 cm)}}{\text{SOC (15-30 cm)}}$$

Plowed soils tend to have values near 1

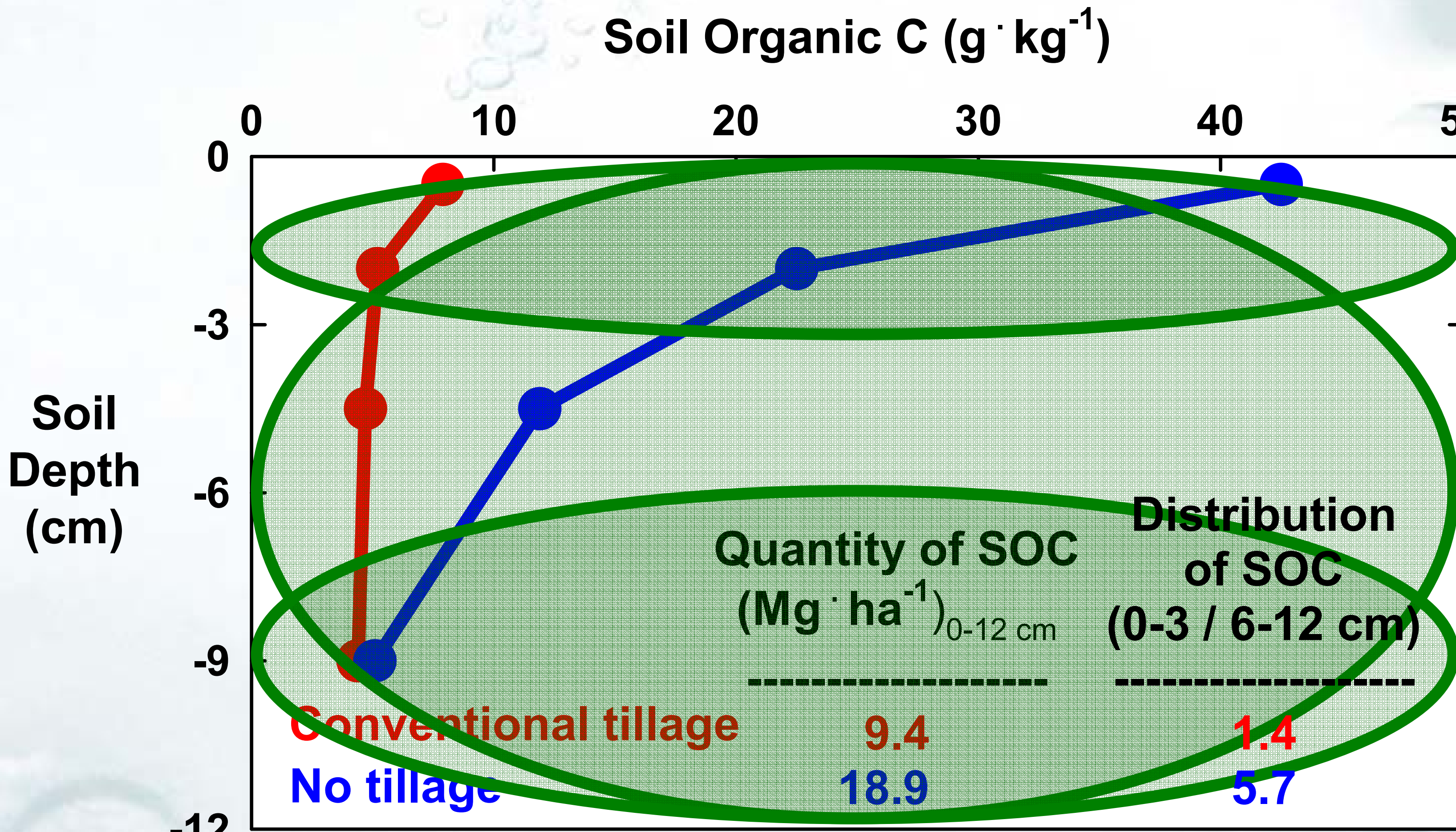
Why is stratification ratio of soil organic C important?

Most important in soils with low native organic matter (e.g. subtropical and coarse-textured soils)



Franzluebbers (2002) Soil Till. Res. 66:95-106

Stratification ratio of soil organic C



NT / CT 2.0 4.1

Franzluebbers (2002) Soil Till. Res. 66:197-205

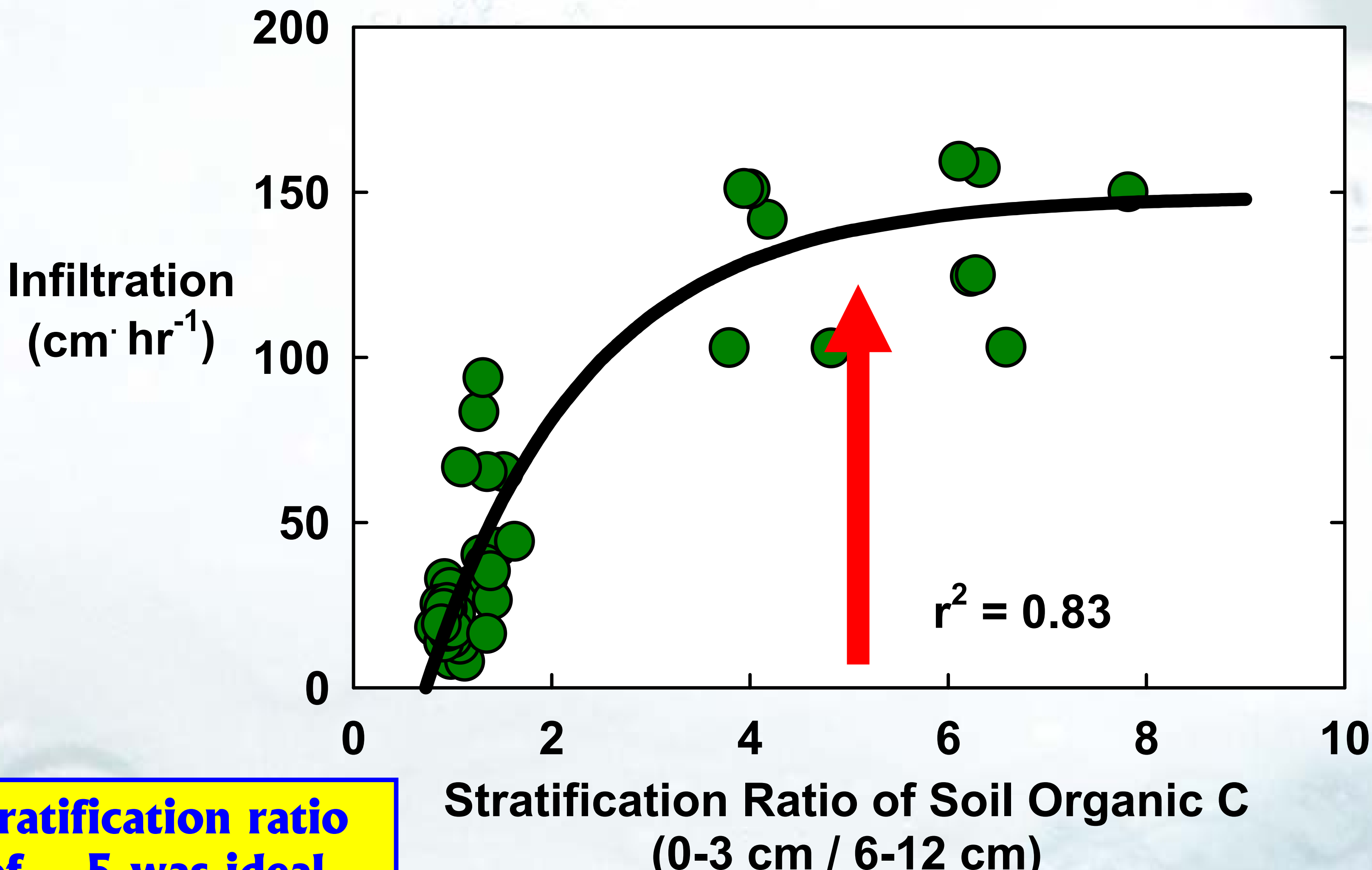
Effect of organic C on water infiltration

	Infiltration Rate ($mm\ min^{-1}$)		
	CT		NT
2x quantity Sieved	2.7	<	3.8
4x distribution Intact	2.2	<<	8.2

Greater rate of infiltration due to stratified distribution of organic C, rather than quantity of organic C

Franzluebbers (2002) Soil Till. Res. 66:197-205

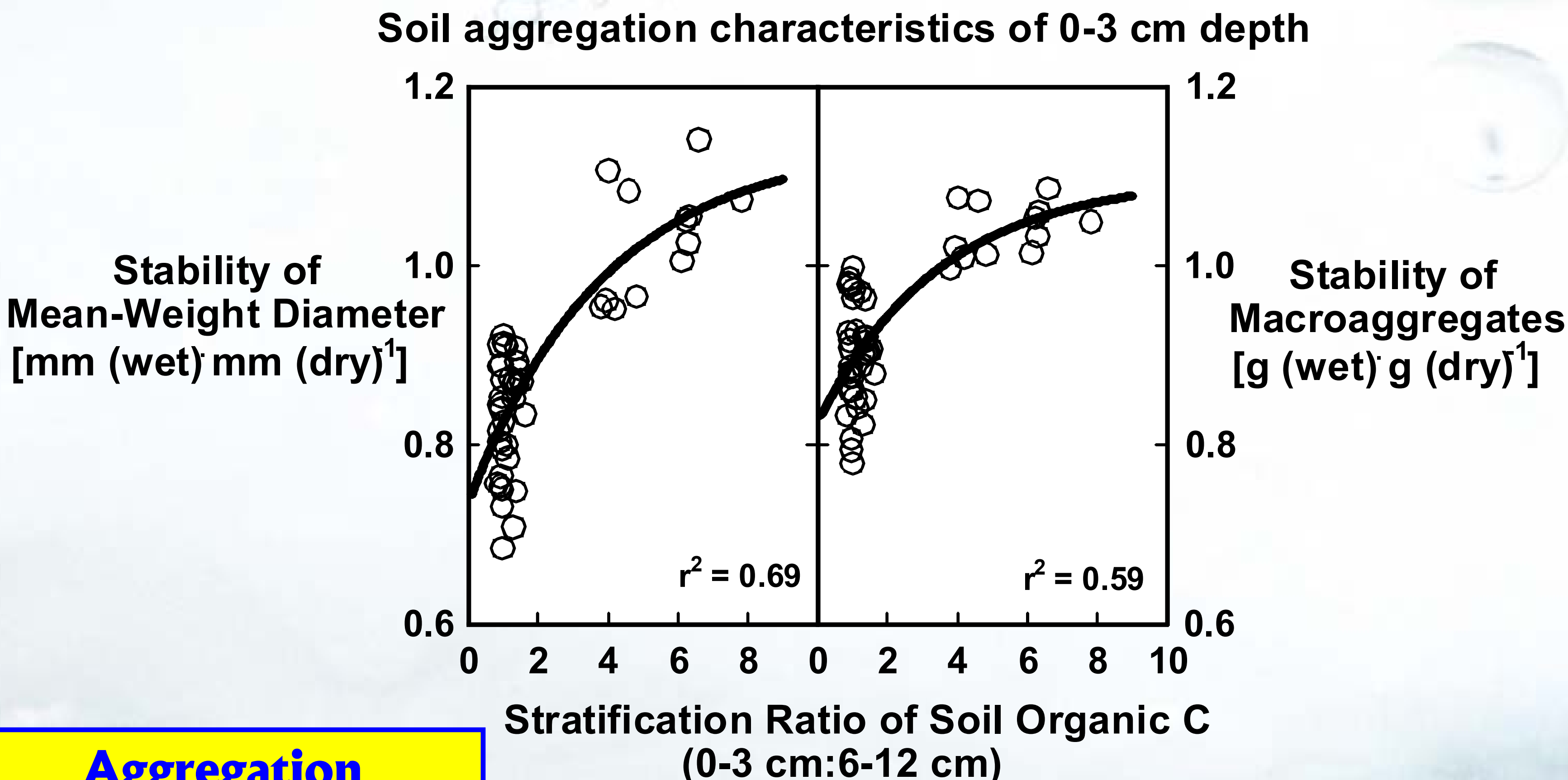
Relationship of stratification ratio of soil organic C to water infiltration



Stratification ratio of ~5 was ideal

Data from Franzluebbers (2002) Soil Till. Res. 66:197-205

Relationship of stratification ratio of soil organic C to surface-soil aggregation

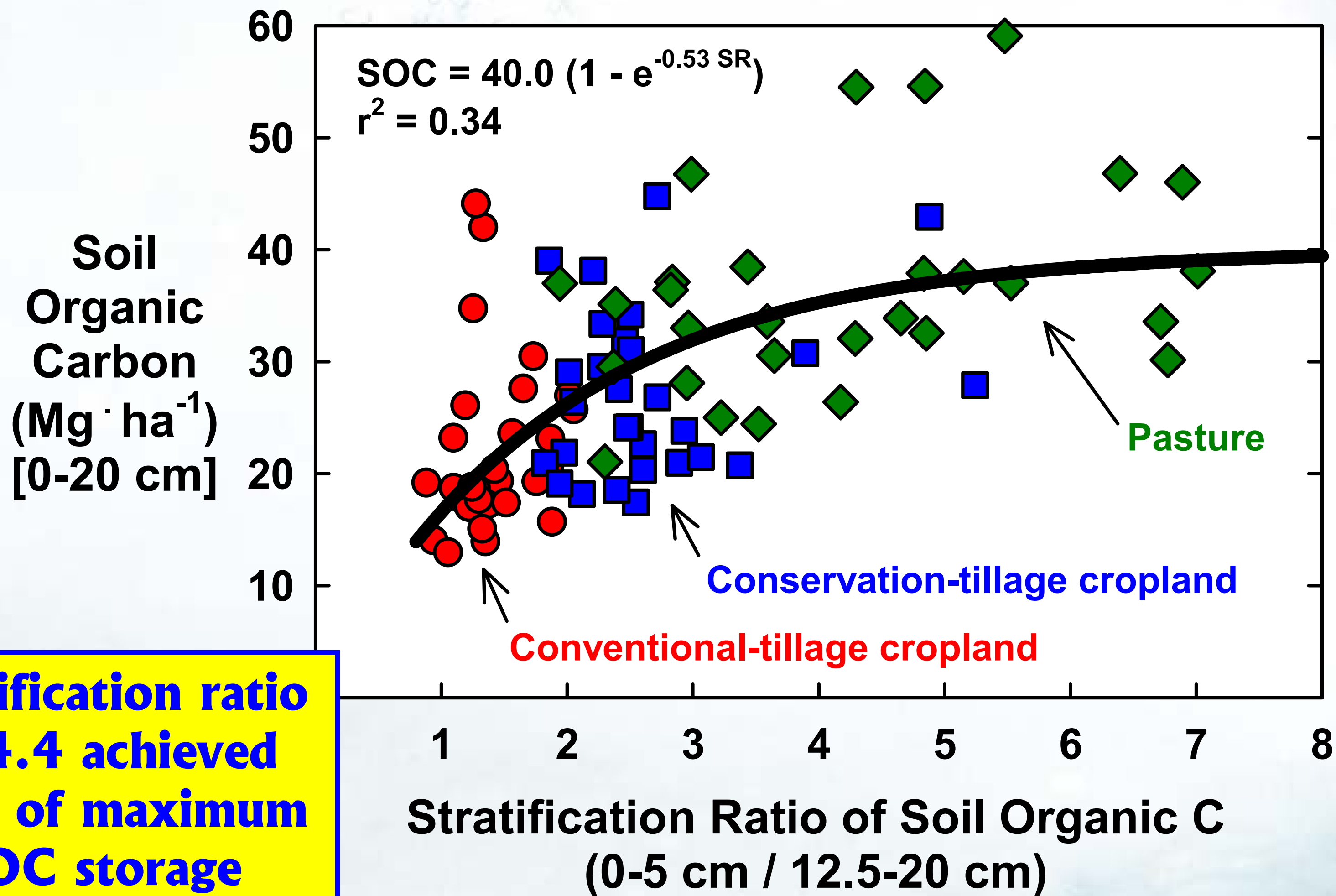


Aggregation response consistent with infiltration!

Data from Franzluebbers (2002) Soil Till. Res. 66:197-205

la era del ecoprogreso
XVII CONGRESO AAPRESID

Relationship of stratification ratio of soil organic C to soil C stock accumulation

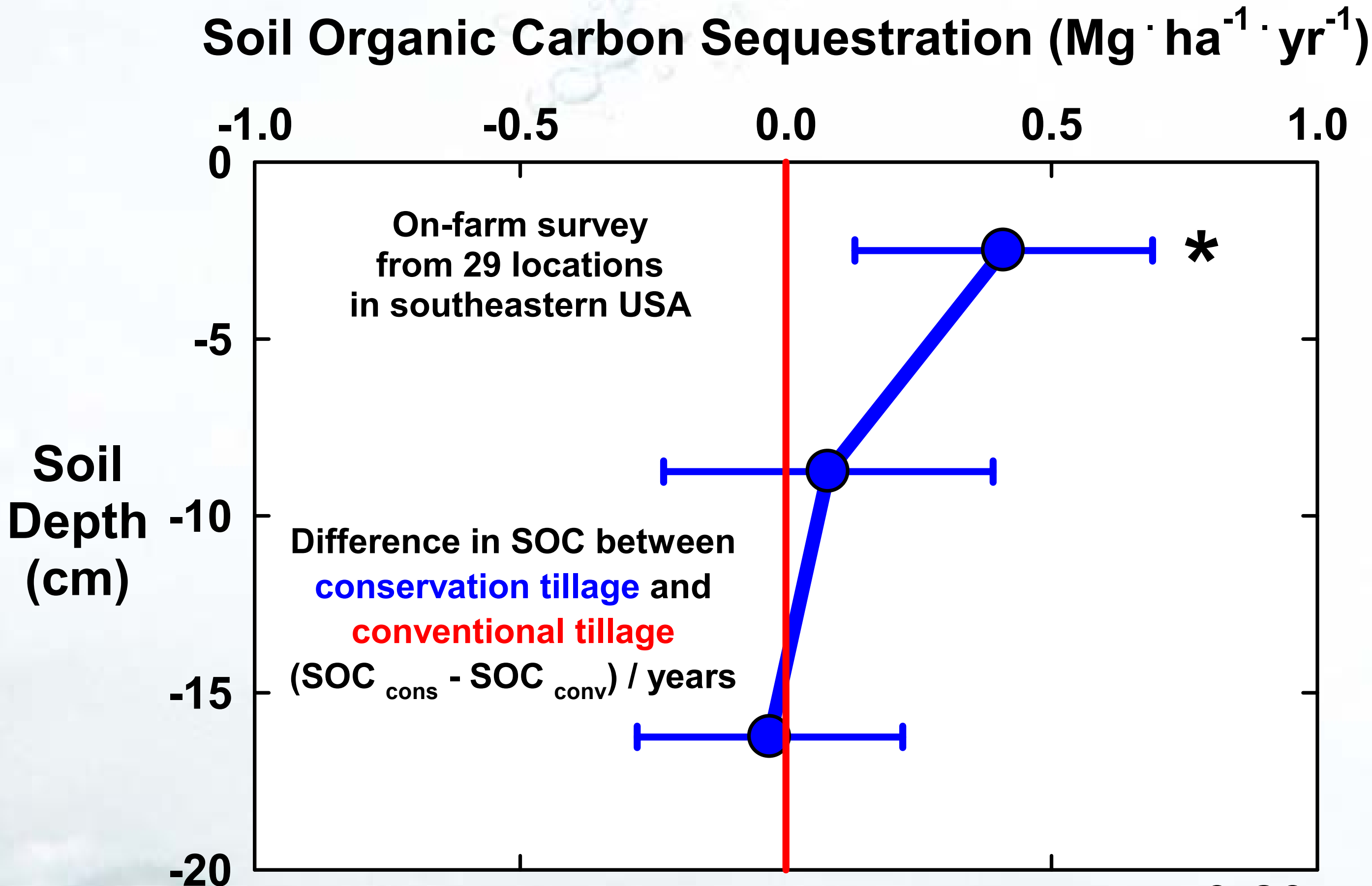


Stratification ratio of 4.4 achieved 90% of maximum SOC storage

Data from Causarano et al. (2008) Soil Sci. Soc. Am. J. 72:221-230

Calculating soil organic C sequestration

Calculation of soil C sequestration by difference

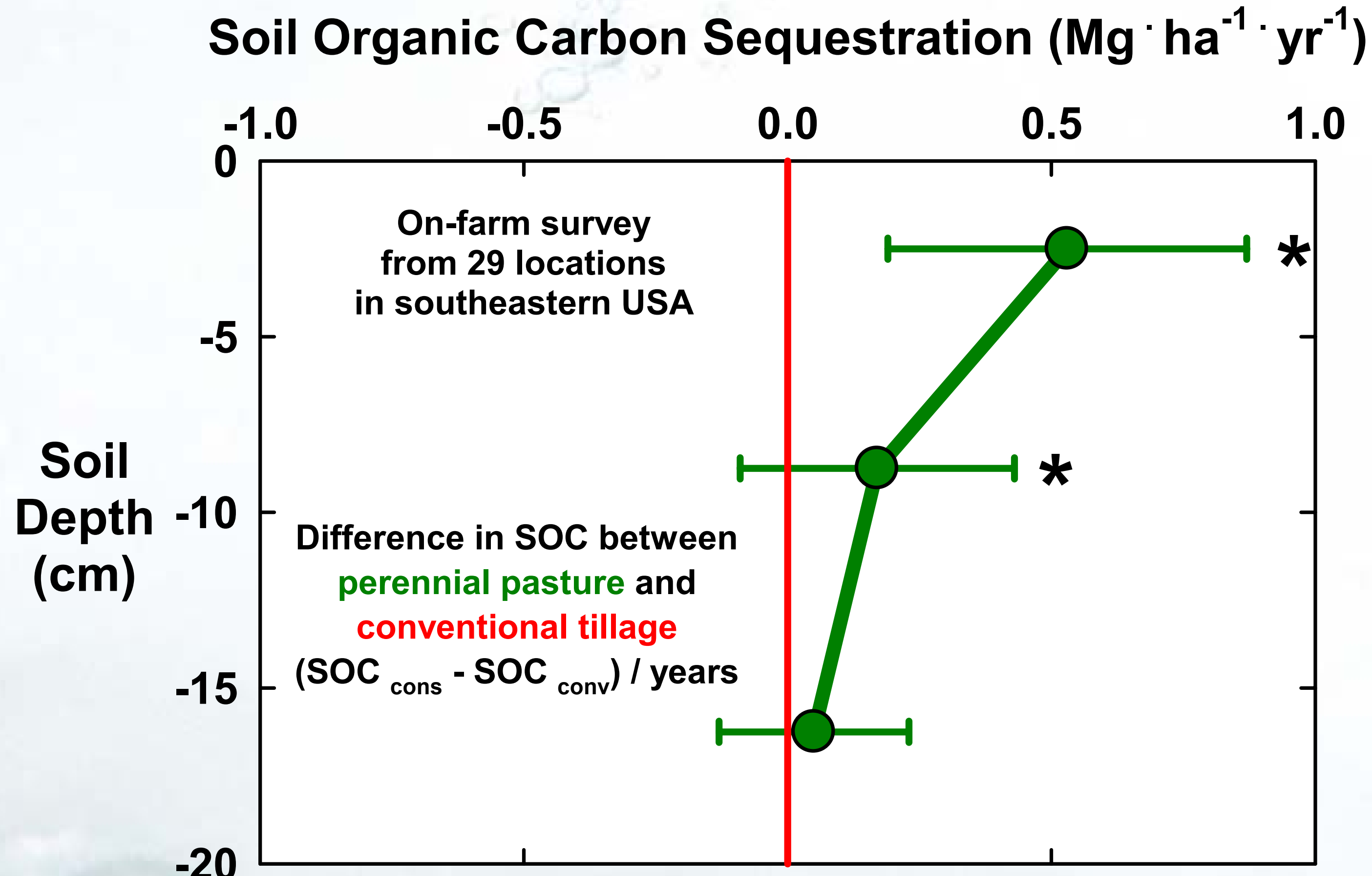


	Sequestration of SOC ($Mg\ ha^{-1}\ yr^{-1}$)
	0.41
	0.08
	-0.03
0-20 cm	0.45 *

Field survey – AL, GA, SC, NC, VA
Ultisols, Alfisols, Inceptisols
12 ± 6 years of conservation tillage
Cotton, corn, soybean, peanut

Data from Causarano et al. (2008)
Soil Sci. Soc. Am. J. 72:221-230

Calculation of soil C sequestration by difference

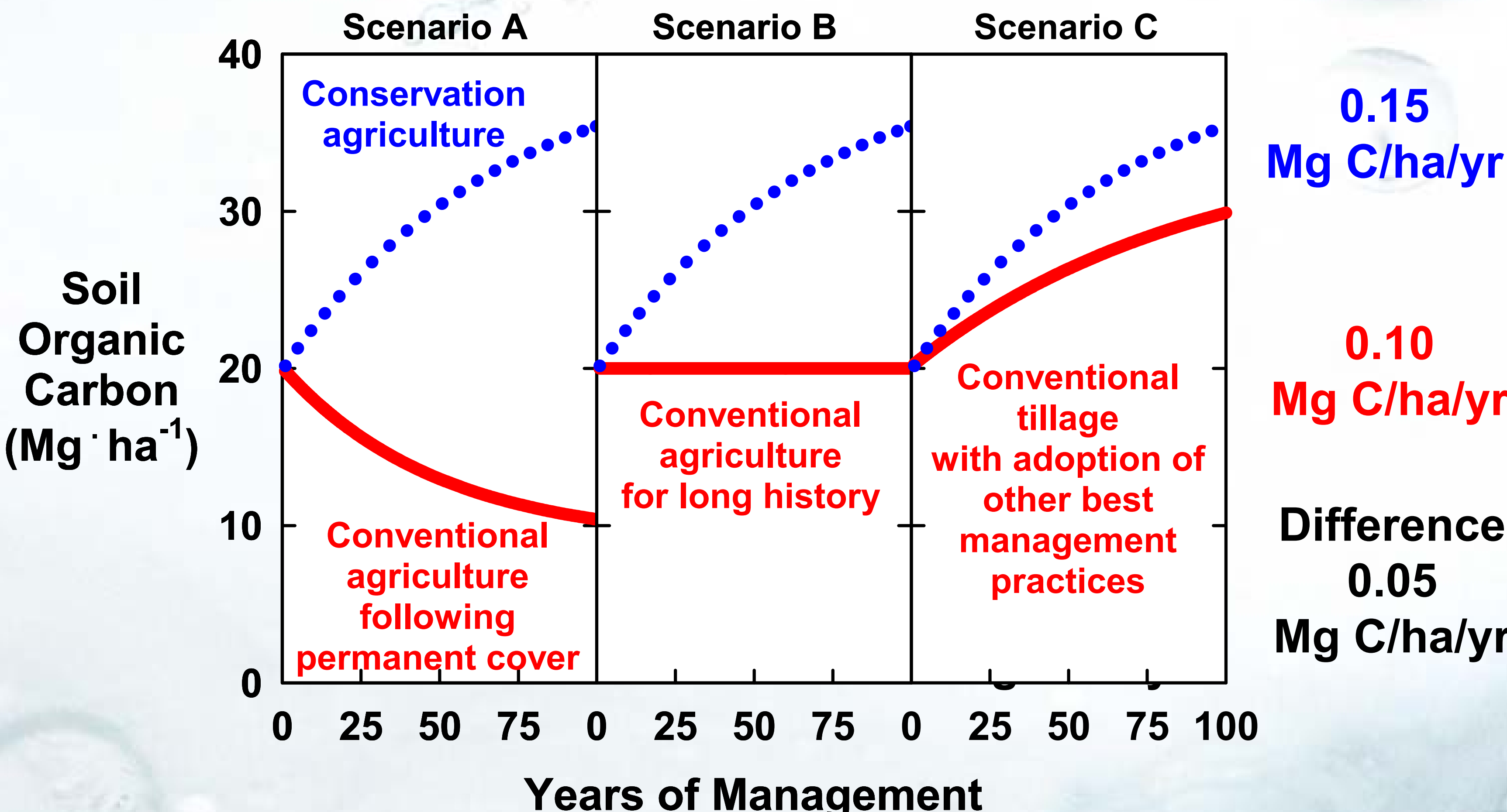


Depth	Sequestration of SOC ($Mg\ ha^{-1}\ yr^{-1}$)
	0.53
	0.17
	0.05
0-20 cm	0.74 *

Field survey – AL, GA, SC, NC, VA
Ultisols, Alfisols, Inceptisols
12 ± 6 years of conservation tillage
Cotton, corn, soybean, peanut

Data from Causarano et al. (2008)
Soil Sci. Soc. Am. J. 72:221-230

Calculation of soil C sequestration by change with time



Temporal and comparative approaches of value; in combination best!

Effect of crop type and sequence on N_2O emission

Emission (kg N_2O-N ha^{-1})

Crop rotation	Crop		
	Corn	Soybean	Wheat
Monoculture	2.62 $\pm$ 1.82	0.84 $\pm$ 0.52	0.51 $\pm$ 0.15
CO_2 equivalence (Mg C ha^{-1} yr^{-1})	0.33	0.11	0.06
Corn/soybean	1.34 $\pm$ 0.52	0.70 $\pm$ 0.43	–
	0.17	0.09	
Corn/soybean/wheat	1.64 $\pm$ 0.76	0.73 $\pm$ 0.24	0.72 $\pm$ 0.33
	0.21	0.09	0.09

Woodslee ON
Brookston clay loam
In Years 2, 3, and 4
Fertilizer – 170 kg N/ha corn,
83 kg N/ha wheat,
none for soybean

Importance of (1) N fertilizer rate, (2) type and amount of residue from previous crop, and (3) residual N

Data from Drury et al. (2008) Can. J. Soil Sci. 88:163-174

Effect of cropping, tillage, and fertilization on N_2O emission

Emission (kg N_2O-N ha^{-1})

Condition	Annual crops / fall incorporation	Annual crops / not incorporated	Perennial crops / not incorporated
Winter/spring (n= 6-10)	2.41 ± 1.79	1.19 ± 0.79	0.29 ± 0.39
CO_2 equivalence (Mg C ha^{-1} yr^{-1})	0.31	0.15	0.04

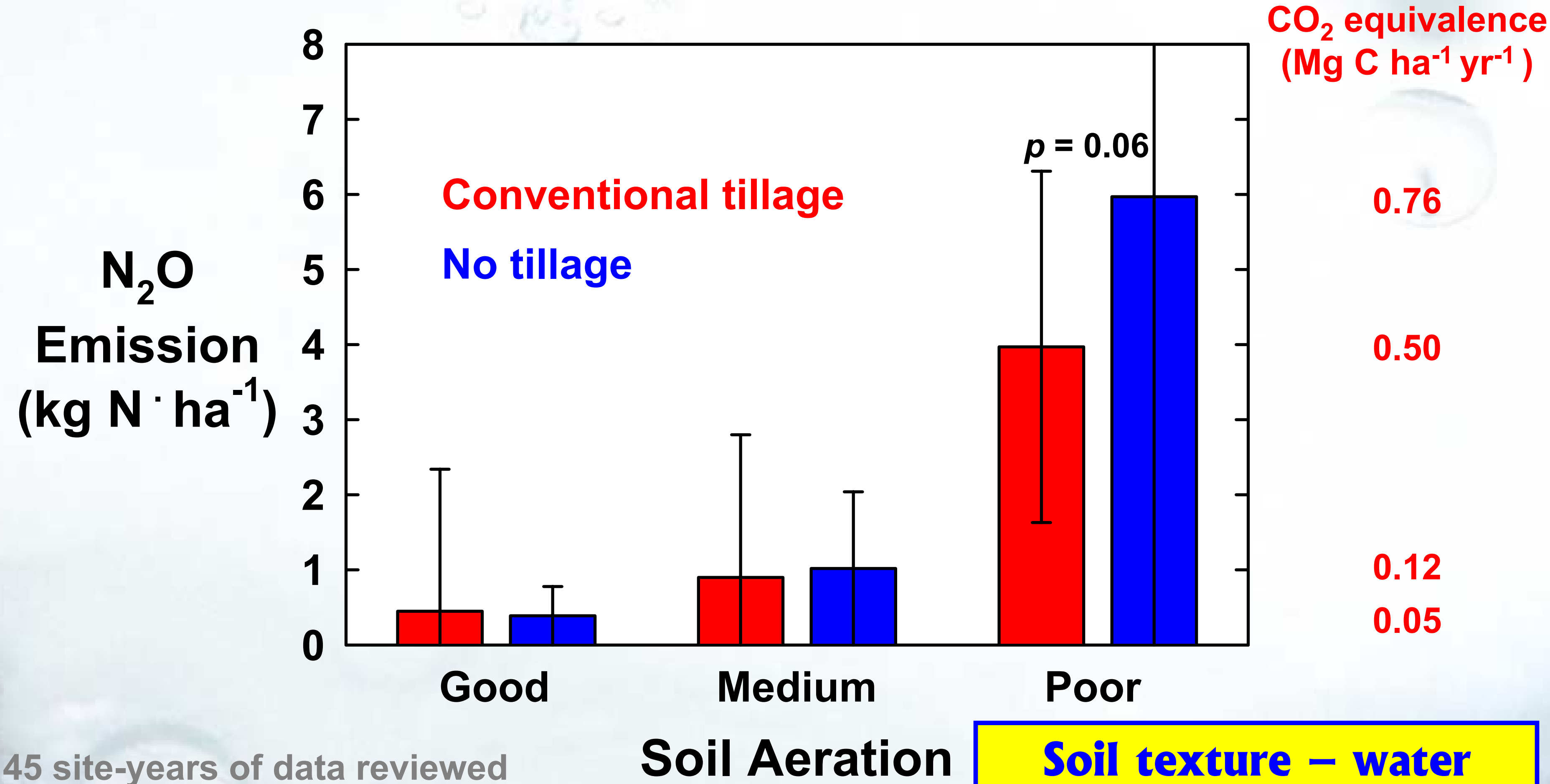
Condition	Moldboard plow	No tillage
Tillage (n=15)	1.60 ± 3.16	1.96 ± 4.66
	0.20	0.25

Condition	− N fertilizer	+ N fertilizer
Annual crops (n=14-57)	1.53 ± 1.00	2.82 ± 2.78
Perennial crops (n=6-9)	0.16 ± 0.21	0.62 ± 1.10
	0.19	0.36
	0.02	0.08

Review of eastern Canada studies

Data from Gregorich et al. (2005) Soil Till. Res. 83:53-72

Interaction of tillage and soil type on N2O emission

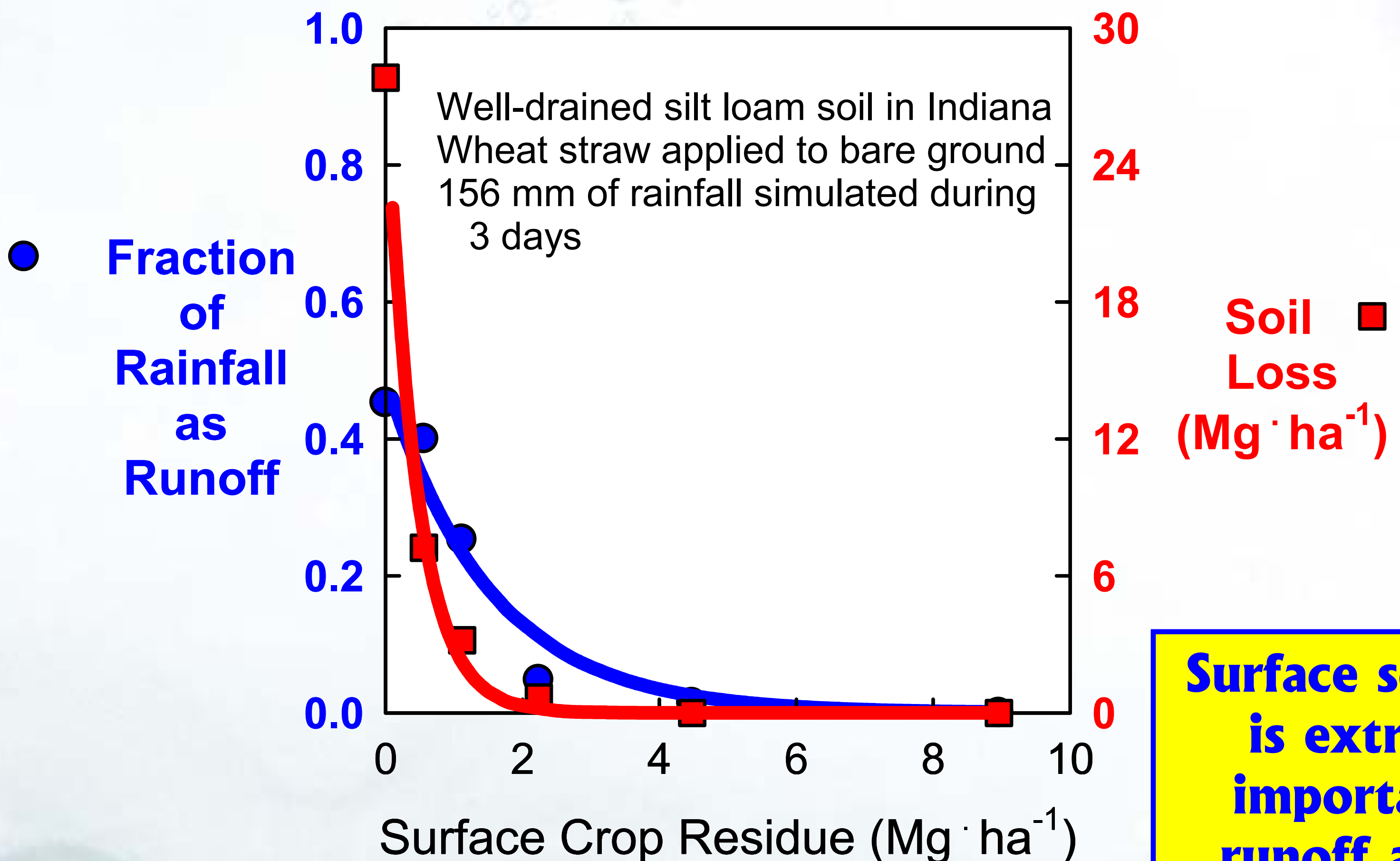


Soil texture – water management important

45 site-years of data reviewed
Brazil, Canada, France, Japan, New Zealand, United Kingdom, USA

Data from Rochette (2008) Soil Till. Res. 101:97-100

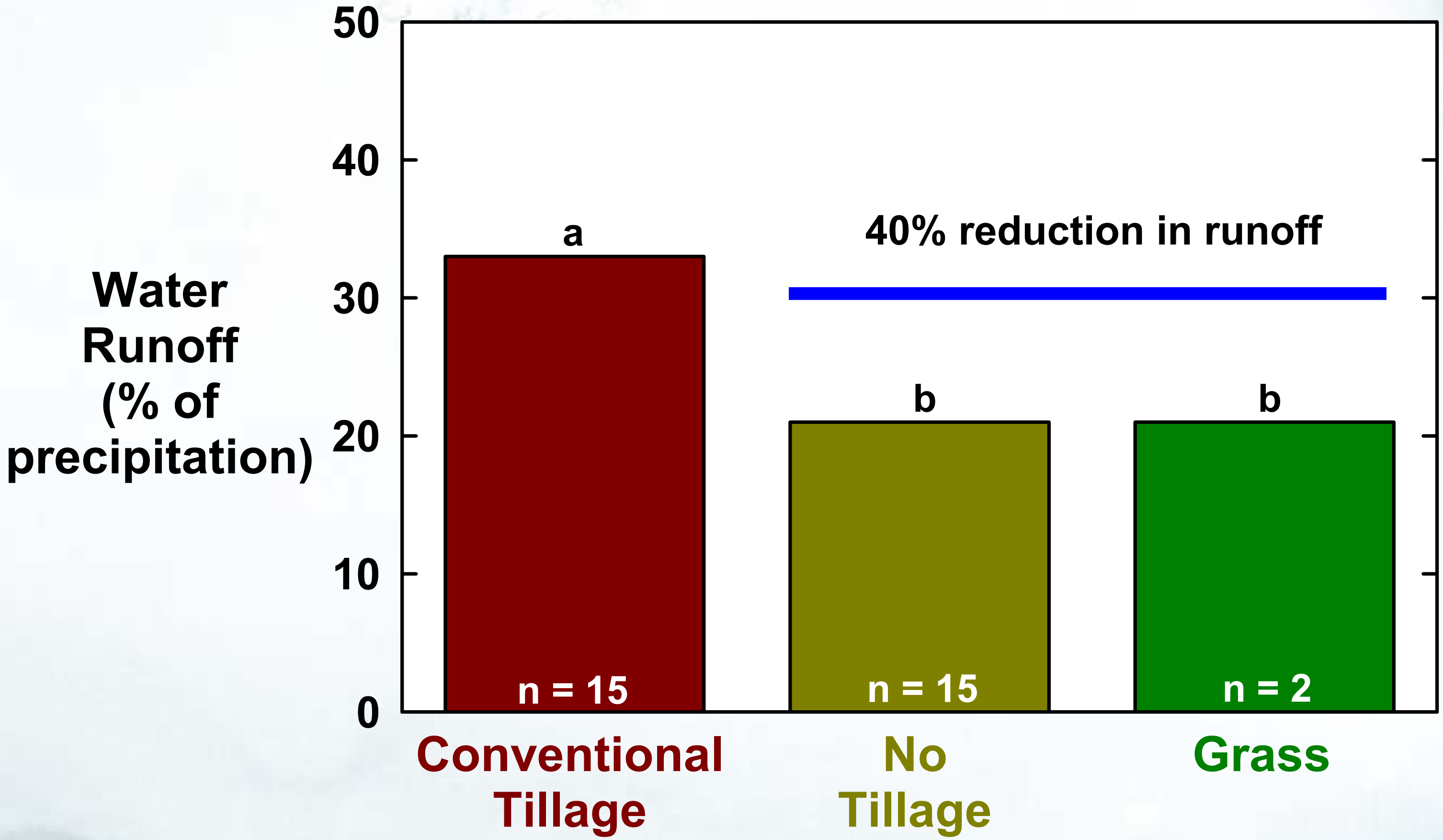
Soil organic C and its relationship with water quality



Surface soil cover is extremely important for runoff and soil erosion control

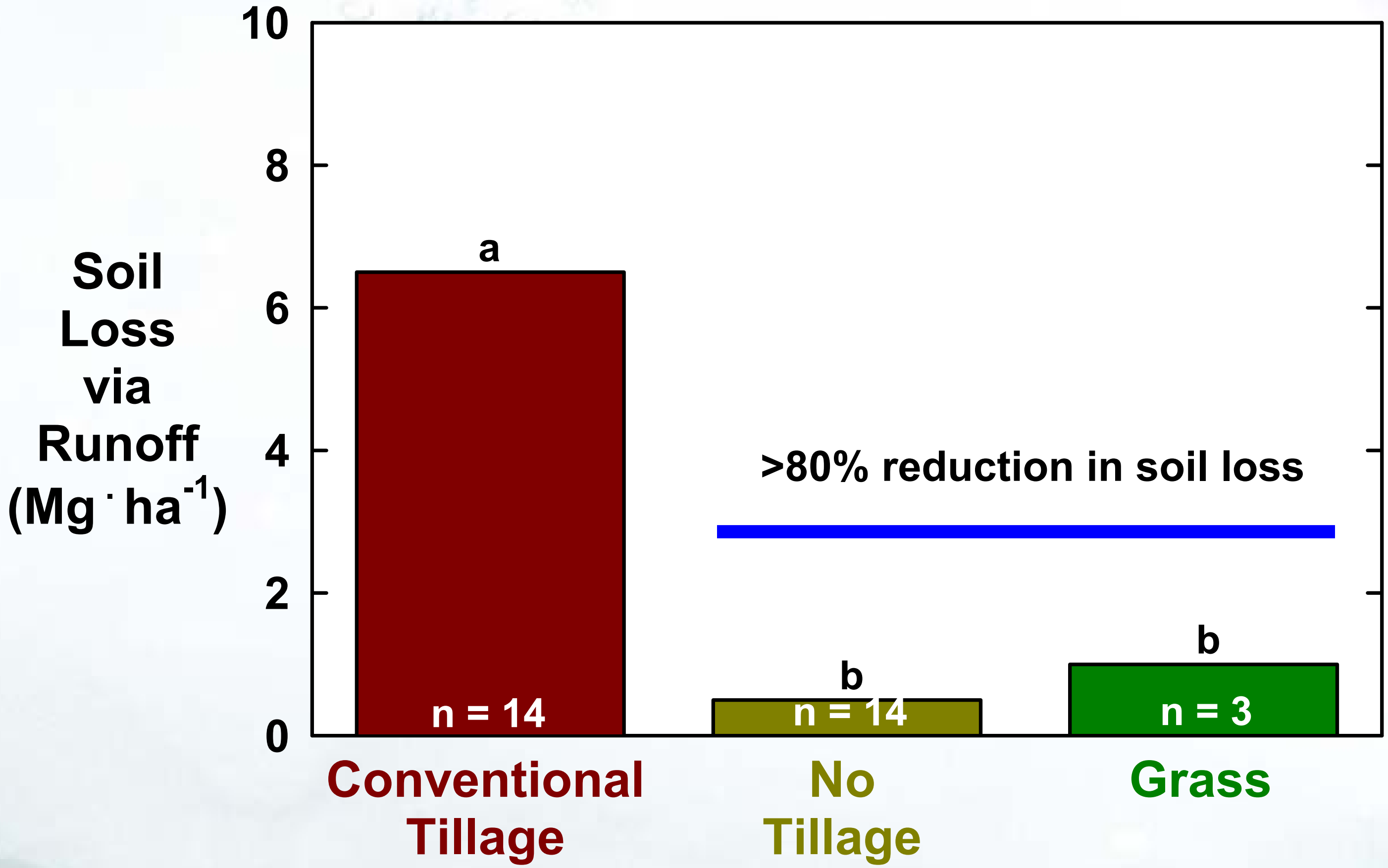
Data from Mannering and Meyer (1963) Soil Sci. Soc. Am. Proc. 27:84-86

Water runoff relative to land use



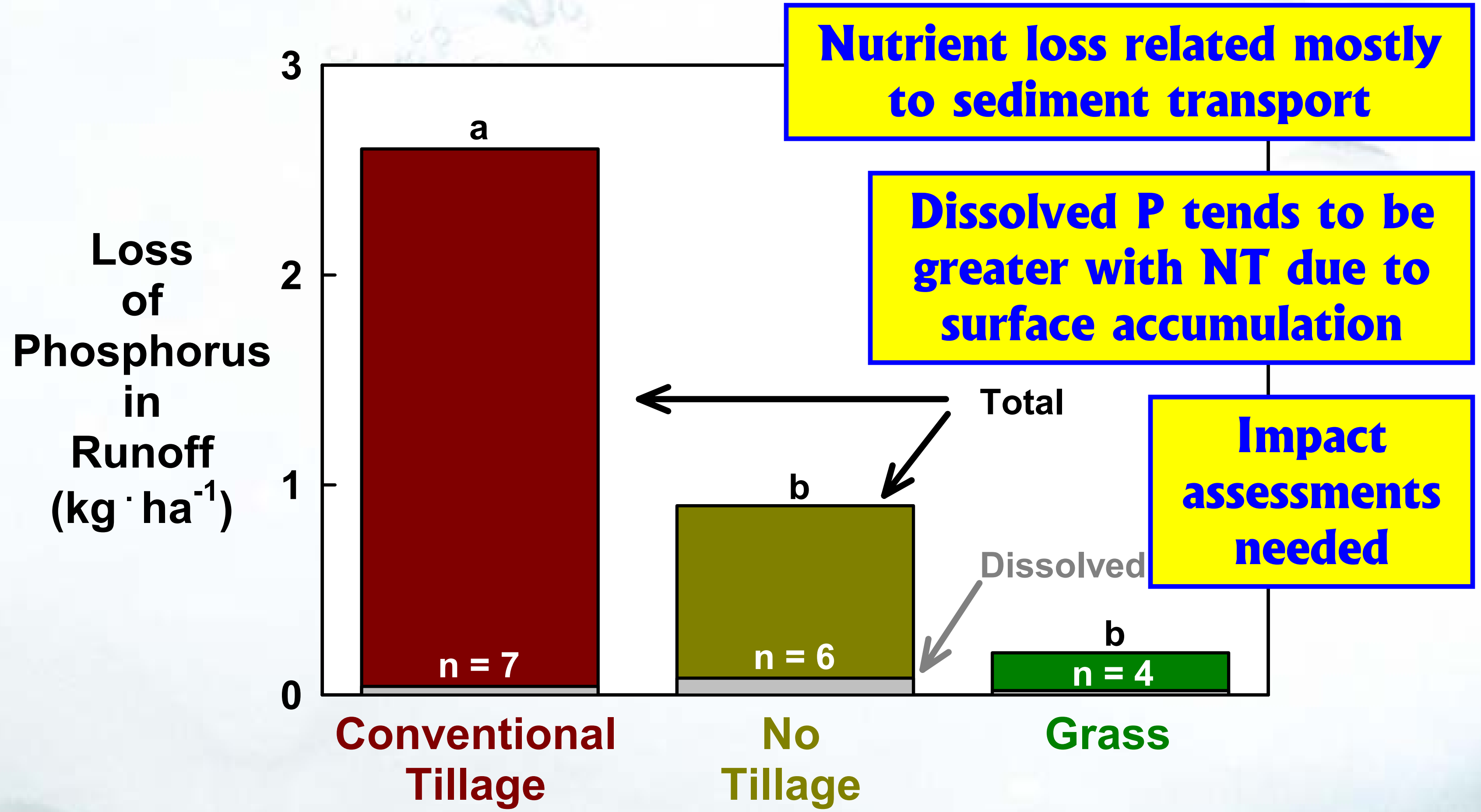
Data from multiple sources (n= __)
Reported in Franzluebbers (2008) J. Integr. Biosci. 6:15-29

Soil loss relative to land use



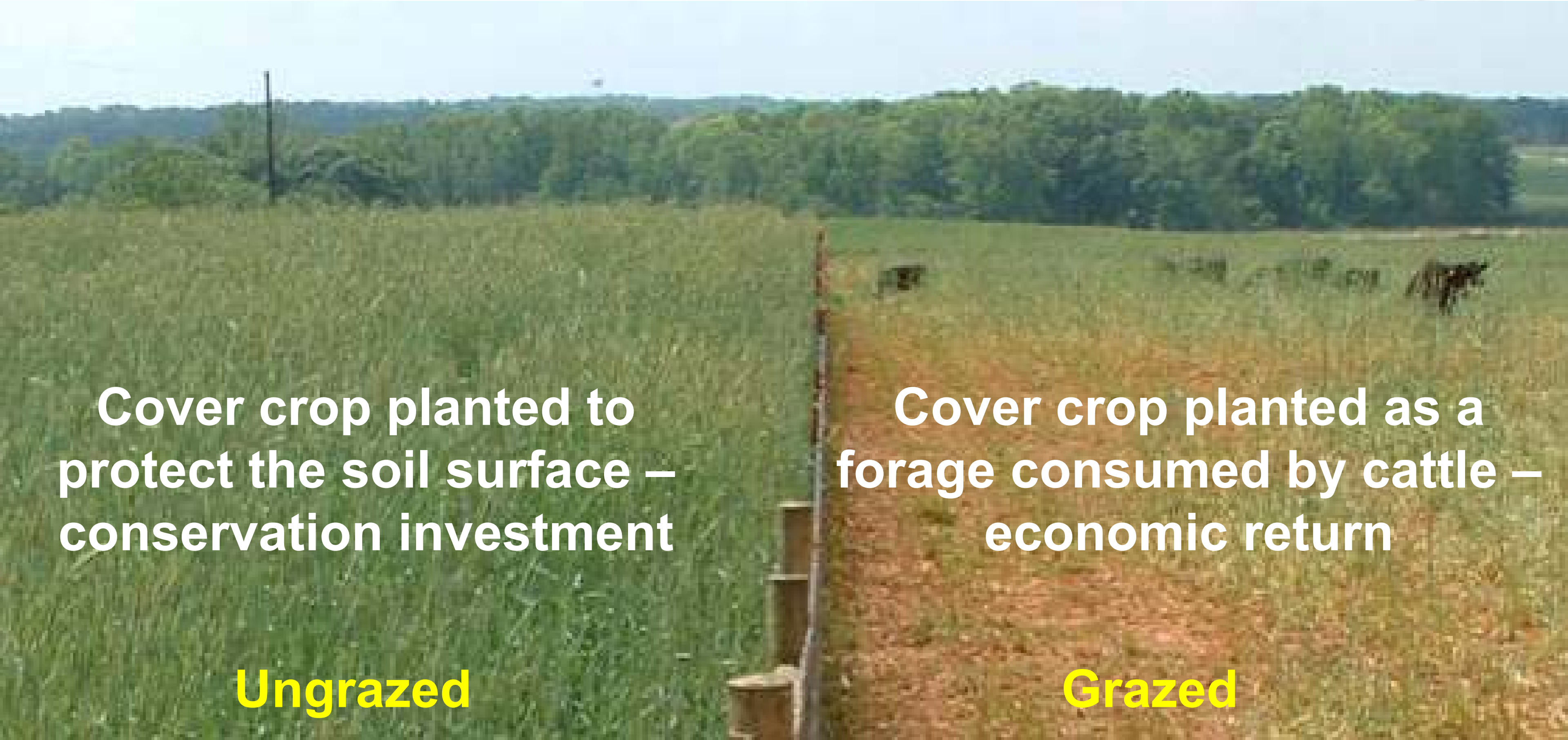
Data from multiple sources (n= __)
Reported in Franzluebbers (2008) J. Integr. Biosci. 6:15-29

Phosphorus loss relative to land use

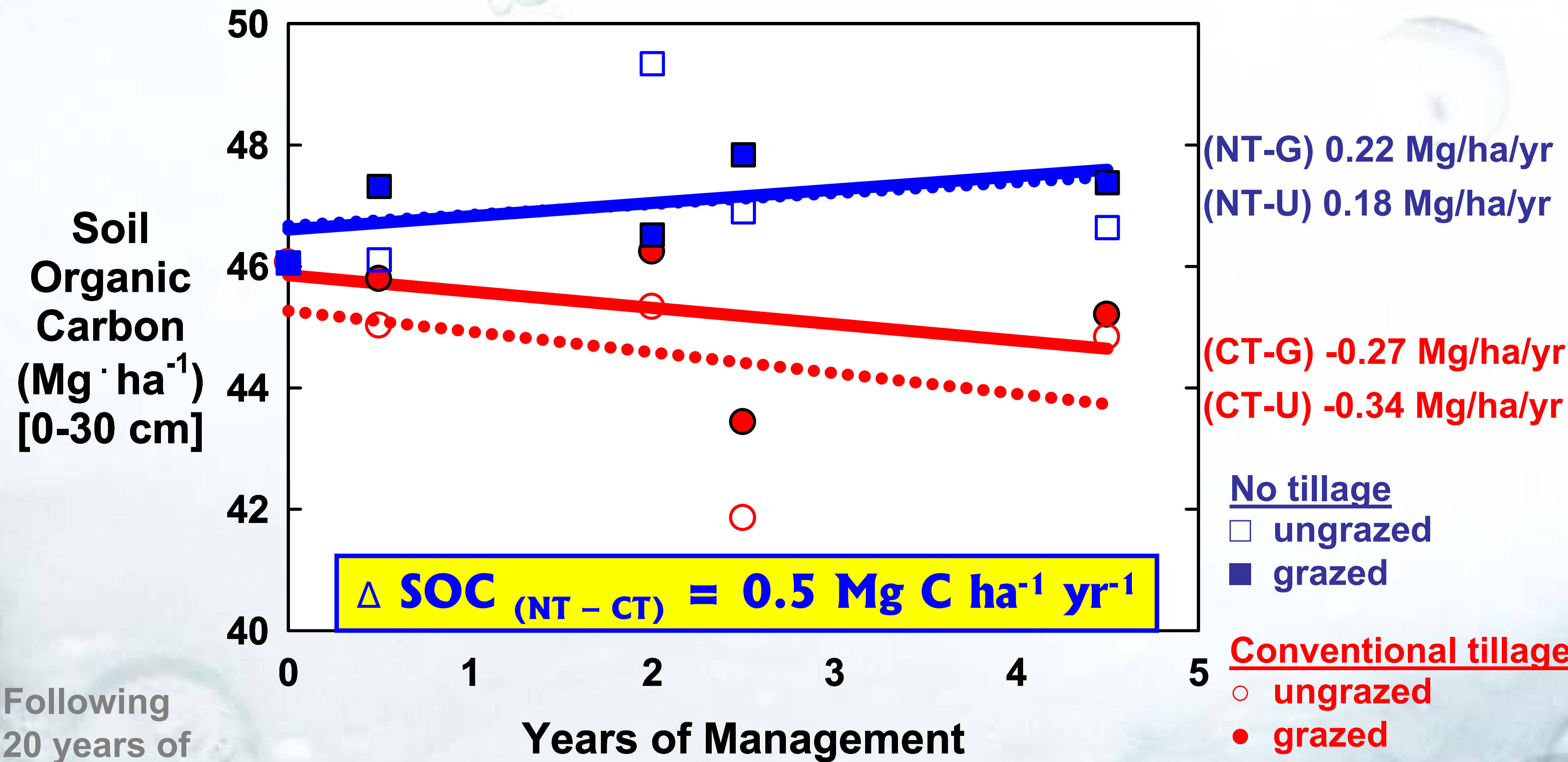


Data from multiple sources (n= __)
Reported in Franzluebbers (2008) J. Integr. Biosci. 6:15-29

Integrated crop–livestock systems



Effect of tillage and grazing on soil organic C



Following 20 years of tall fescue pasture

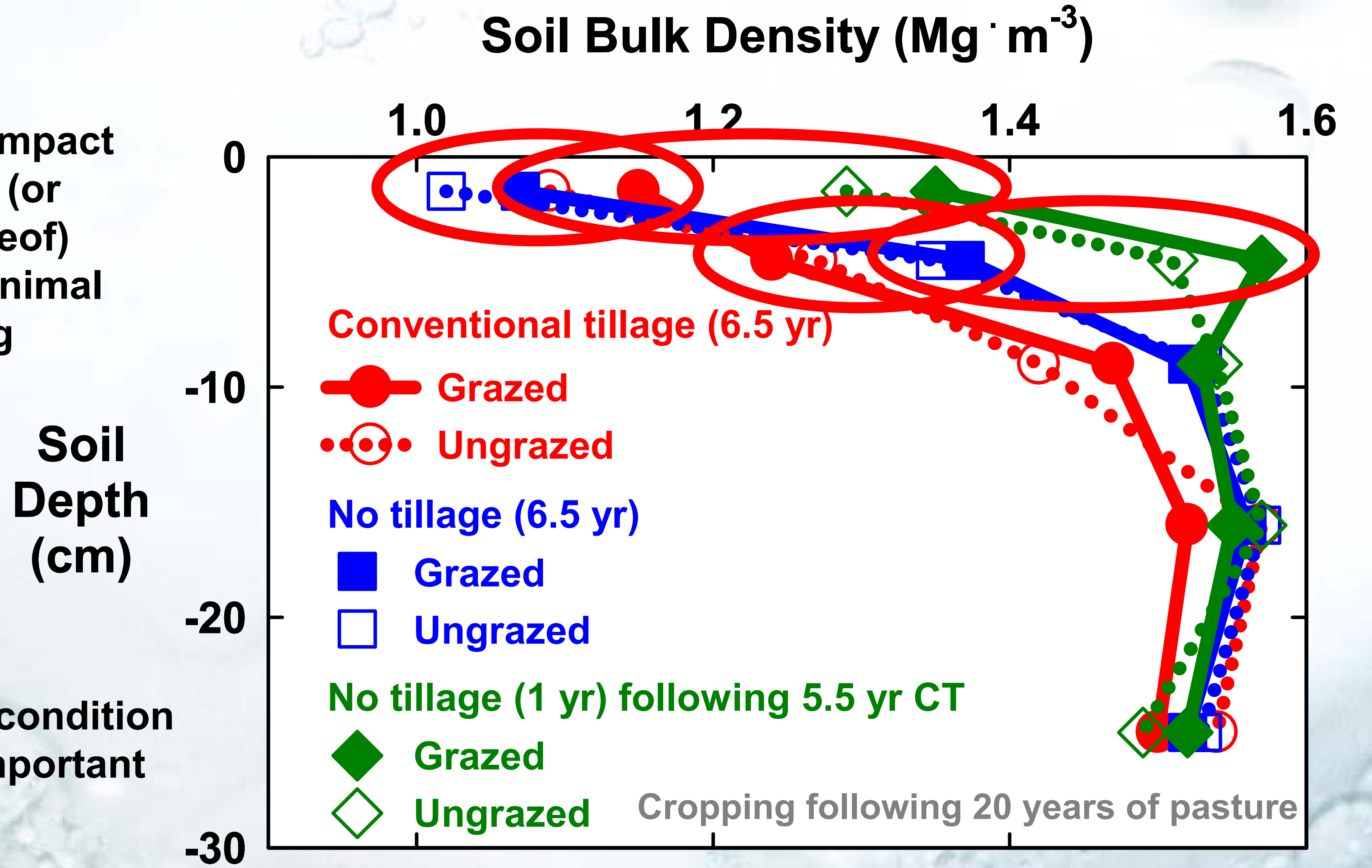
Franzluebbers and Stuedemann (2008) Soil Sci. Soc. Am. J. 72:613-625

la era del ecoprogreso
XVII CONGRESO AAPRESID

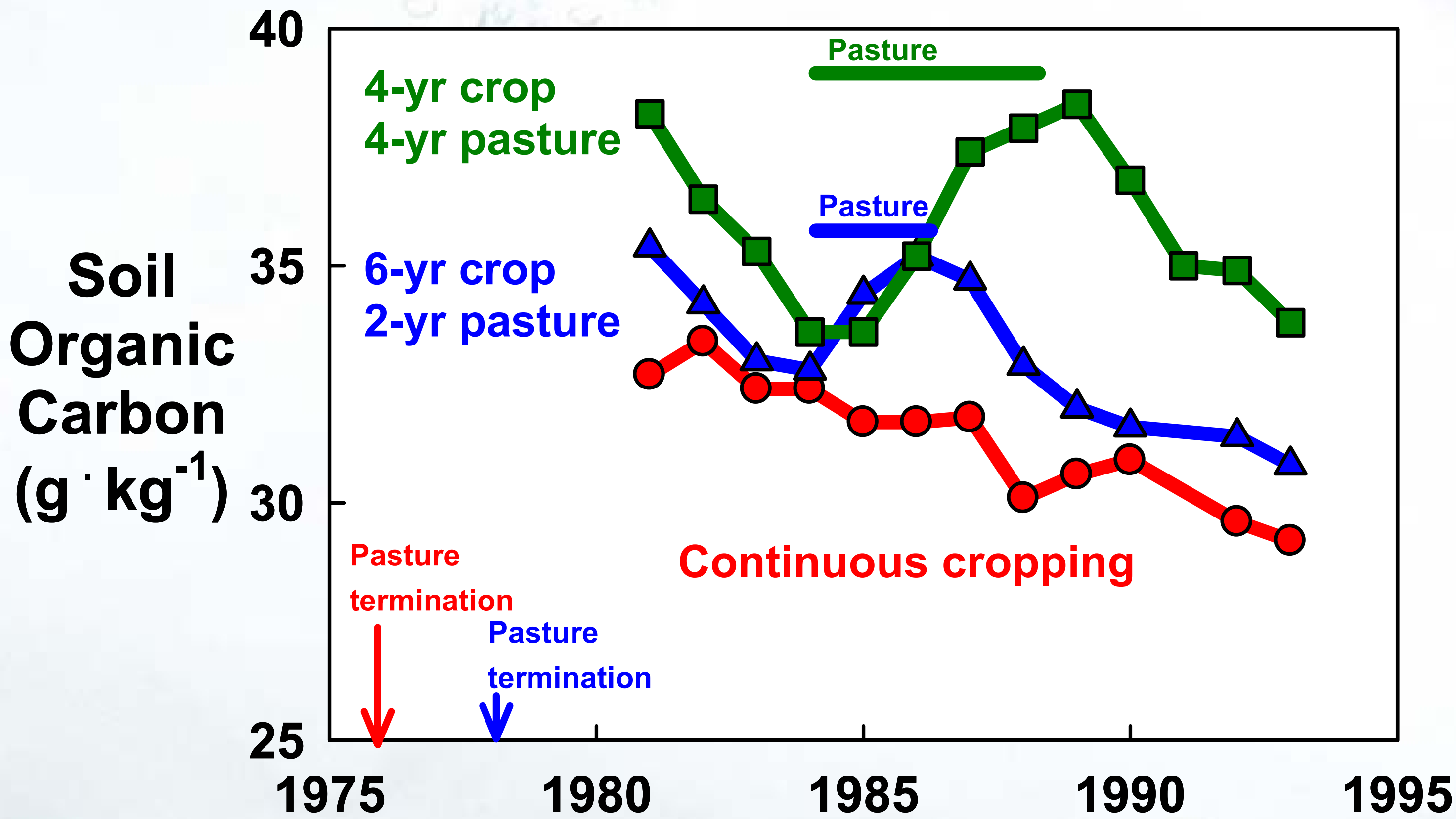
Effect of tillage and grazing on bulk density

Greater impact of tillage (or lack thereof) than of animal trampling

Starting condition for NT important



Effect of pasture–crop rotation on soil organic C



Sod-based crop rotations are needed to maintain fertility and soil quality

Data from Studdert et al. (1997) Soil Sci. Soc. Am. J. 61:1466-1472

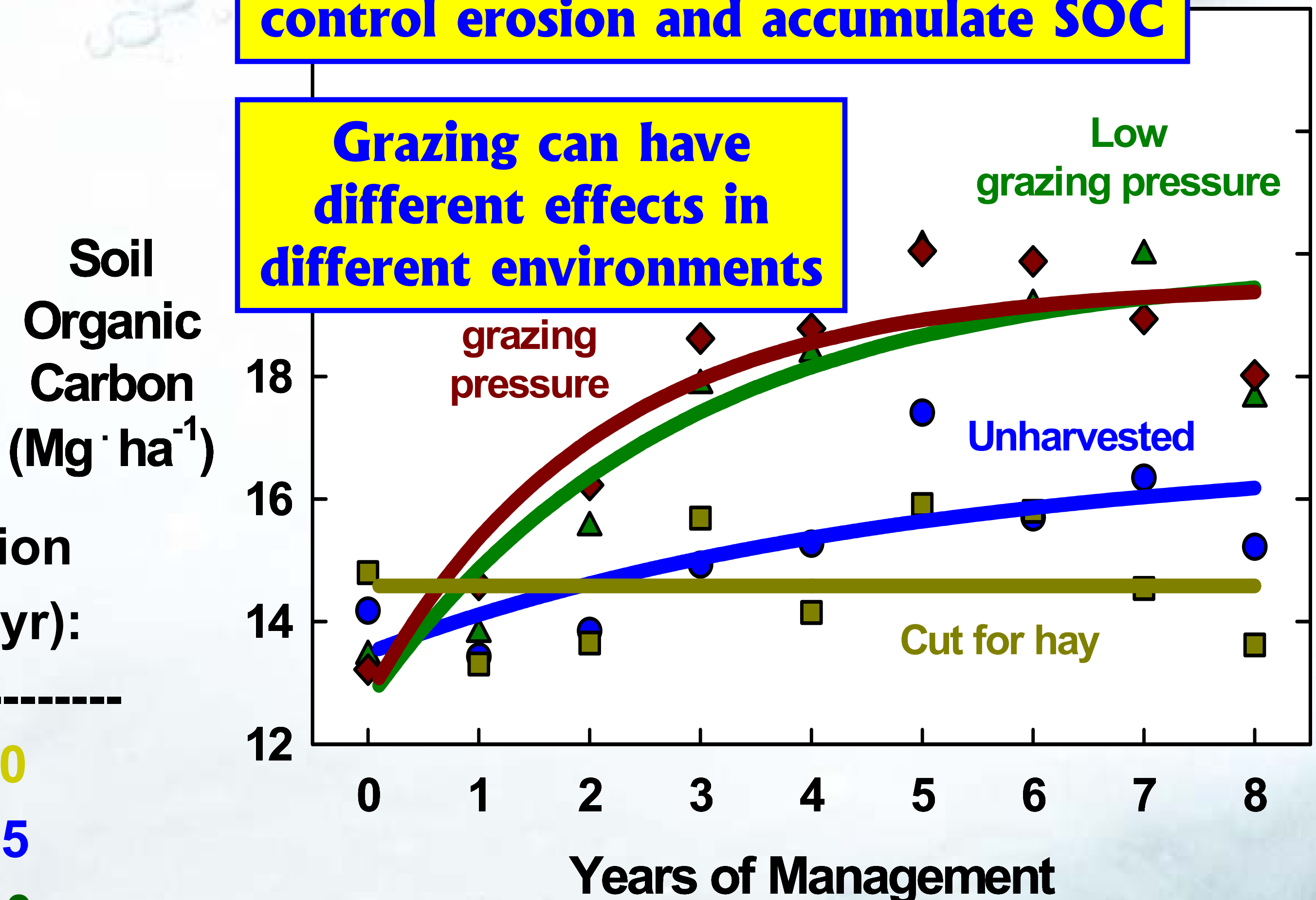
la era del ecoprogreso
XVII CONGRESO AAPRESID

Effect of pasture establishment on soil organic C

Perennial grass is important to control erosion and accumulate SOC

Grazing can have different effects in different environments

Establishment of bermudagrass pasture following long-term cropping in Georgia USA
(16 °C, 1250 mm)



Soil C sequestration ($Mg\ ha^{-1}\ yr^{-1}$) (0-5 yr):

Hayed	0.30
Unharvested	0.65
Grazed	1.40

Franzluebbers et al. (2001) Soil Sci. Soc. Am. J. 65:834-841 and unpublished data

Summary of integrated crop–livestock systems with conservation tillage

Conservation of soil and water resources is a necessity in our world of ever-changing and competing human activities

Meeting the food and fiber demands of a growing world population will only become more difficult with competing energy and natural resource commitments

Integration of crops and livestock has great potential to improve resource efficiency of agricultural production around the world

Sod-based crop rotations effectively improve soil and water quality

Cover crops offer unique opportunities to integrate livestock grazing with cropping systems

Some cases of integration have been developed, but much more research is needed to optimize systems within unique local and regional conditions

Summary and conclusions

- ✓ Soil organic matter is an essential component of high quality soil.
- ✓ Organic matter is often enriched at the soil surface with conservation agricultural management.
- ✓ Both no tillage and pasture-crop rotations can help build and maintain soil organic matter.
- ✓ Highly stratified soil organic matter with depth is indicative of soils' ability to preserve environmental quality, particularly through water quality protection and sequestration of atmospheric C into soil organic C.

Acknowledgements

Funding

Agricultural Research Service (ARS)
US-Department of Energy
Madison County Cattleman's Association
USDA-National Research Initiative – Soil Processes
Cotton Incorporated
Georgia Commodity Commission for Corn
The Organic Center
ARS GRACEnet team